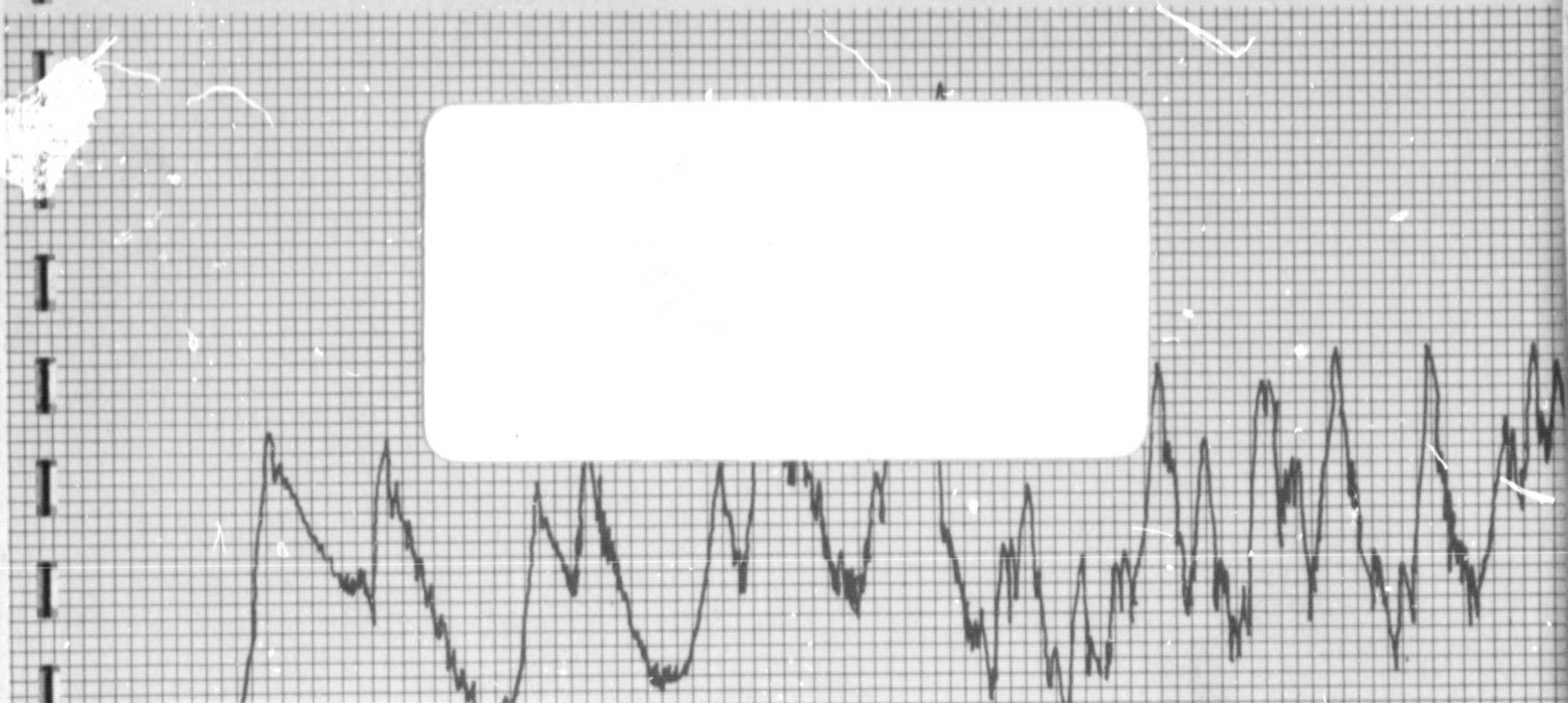
WYLE LABORATORIES
SCIENTIFIC SERVICES AND SYSTEMS GROUP



(NASA-CR-161960) BASELINE STUDIES ON THE FEASIBILITY OF DETECTING A COAL/SHALE INTERFACE WITH A SELF-POWERED SENSITIZED PICK Final Report (Wyle Labs., Inc.) 98 p HC A05/MF A01 CSCL 08I G3/43

N82-17553

Unclas

11685

research REPORT

WYLE LABORATORIES - RESEARCH STAFF
TECHNICAL MEMORANDUM TM 81-3

BASELINE STUDIES ON THE FEASIBILITY OF DETECTING A COAL/SHALE INTERFACE WITH A SELF-POWERED SENSITIZED PICK

by

Granville R. Anderson, II

Work Performed Under Contract DEN8-000011

for

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

by

WYLE LABORATORIES
RESEARCH & ENGINEERING DIVISION
SCIENTIFIC SERVICES & SYSTEMS GROUP
7800 GOVERNORS DRIVE, WEST
HUNTSVILLE, ALABAMA 35807

February 19, 1981

COPY NO. 16

FOREWORD

This report was prepared by Wyle Laboratories, Research and Engineering Division, Huntsville, Alabama, under NASA contract DEN8-000011. The author wishes to express his graditude to NASA personnel, Messrs. P. H. Broussard, Jr. and Bill Reed, for their guidance and assistance in conducting these experimental investigations. The Department of Energy, Bruceton, Pennsylvania, and Peabody Coal Company, Belleville, Illinois, are hereby acknowledged for their aid in the acquisition and supply of raw materials required for these experiments.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

A conventional longwall mining pick was instrumented and cutting force magnitudes were determined for a variety of materials, including Illinois #6 coal, shale-type materials, and synthetic coal/shale materials. The feasibility of utilizing a sensitized pick to discriminate between cutting coal and roof material during the longwall mining process was investigated.

Section 1

INTRODUCTION

The abundance of coal reserves within the continental boundaries of the United States has led to the identification of coal as a solution to immediate energy needs as well as a long-term source of energy. These vast deposits of coal are not readily accessable, however, and require large investments for the mining machinery necessary to extract the coal and the manpower required to operate mining equipment. In addition, present mining technology exposes operational personnel to an extremely hazardous environment. As a result, research is being conducted to improve the operational characteristics and efficiency of the various types of mining machinery and to reduce the hazards associated with the mine environment.

One of the newest and most productive mining machines utilized to mine coal in the United States is the longwall miner. The National Aeronautics and Space Administration (NASA), George C. Marshall Space Flight Center, in cooperation with the Department of Energy (DOE), is conducting research programs aimed at the development of a semi-automatically controlled longwall mining machine that would increase productivity by eliminating, or reducing, roof material contamination in the coal output and reduce maintenance cost and downtime for repairs directly relatable to cutting roof material. Assisting NASA with their investigations into this area, Wyle Laboratories has conducted an experimental research program under NASA contract DEN8-000011. The experimental investigations were performed at Wyle's Huntsville, Alabama facility utilizing a linear cutting apparatus (LCA) designed and built by Wyle for the

U. S. Department of the Interior, Bureau of Mines. The principal objectives of the program were to

- Qualify the magnitude of the force being exerted on a conventional longwall mining pick when cutting real and artificial coal/roof materials under controlled conditions.

- Formulate and test a variety of synthetic coal/roof shale materials that, when cut, would exhibit cutting force characteristics comparable to those of real coal and roof material.

- Investigate the feasibility of utilizing a sensitized cutting pick that would be able to discriminate between cutting roof material and coal on the basis of cutting force.

This final report documents the work performed and the results obtained under the present contract. Presented in section 2 are the cutting force results for LCA cutting experiments on (1) the existing artificial coal/roof shale materials being utilized at DOE's mock longwall facility at Bruceton, Pennsylvania, (2) real coal from the Illinois #6 coal seam, and (3) real roof shale-type material. Section 3 lists the various synthetic coal/roof material formulae and associated cutting force results. The proposed sensitized pick concept is explained in detail in section 4, and the results of laboratory investigations, along with LCA results, are interpreted with respect to the concept. Finally, conclusions and recommendations are summarized in section 5.

Section 2

LCA CUTTING EXPERIMENTS

The phase 1 LCA experiments consisted of performing a series of ten cuts in a variety of materials. After obtaining a quantity of each material, the required number of samples were prepared for the LCA by encapsulating the material to be cut in a block of gypsum-based cement. Each block was then cut in half utilizing a friction saw to provide a uniform (smooth) material face, which was required to ensure an accurate setting of the depth of cut.

The cutting transient was recorded on one-inch magnetic tape utilizing a Bell & Howell CPR 4010 magnetic tape recorder. The tape recorder was set up to operate on the IRIG intermediate band at 30 ips, providing an operational frequency bandwidth of 0 to 10 kHz. Once the required number of repetitions were performed, each cutting transient was analyzed on a Norland 2001A digital signal analyzer. Each cutting transient was reduced in terms of statistically descriptive quantities, such as peak, mean, standard deviation, and root-mean-square values calculated over the duration of the cut. These results are given in tables A1 and A2 of appendix A. For each material and/or experimental condition, these individual statistical quantities were averaged to produce sample-averaged quantities associated with the number of repetitions. The sample-averaged quantities are also given in appendix A, and are summarized in Tables 1 and 2 for ease of comparison. The cutting transient time histories (except Wyle synthetic formulations) have been plotted and are displayed by cut number in appendix B.

TABLE 1. SAMPLE-AVERAGED CUTTING FORCE RESULTS

Material Type	Depth of Cut (in.)	Cut Duration (sec)	Measured Cutting Force (lbf)			
			Peak Value	Mean Value	Standard Deviation	Root-Mean Square
BSC	½	0.093	1832	282	290	400
	1	0.097	3500	771	585	964
BSS	½	0.098	3163	616	472	781
	1	0.100	6780	1739	1127	2075
ILL #6	1	0.079	2733	585	497	761
IS	½	0.092	3852	632	627	844
	1	0.099	2918	866	673	1051
SCF						
(5/4/½)	1	0.111	1786	432	303	525
(5/4/1)	1	0.114	2813	736	499	884
(5/4/1½)	1	0.120	3935	929	609	1108
(5/4/2)	1	0.122	4073	1124	717	1327
(5/2½/2)	1	0.124	4366	1183	751	1395
(5/3½/1)	1	0.120	3387	871	563	1034
(5/3/1½)	1	0.124	4629	1104	707	1313

BSC - Bruceton Synthetic Coal; BSS - Bruceton Synthetic Shale; ILL #6 - Illinois #6 Coal; IS - Illinois Shale-type Material; SCF - Synthetic Coal Formulation (Coal/Ash/Portland Cement).

TABLE 2. SAMPLE-AVERAGED SENSITIZED PICK RESULTS

Material Type	Depth of Cut (in.)	Cut Duration (sec)	Measured Cutting Parameters (volts)			
			Peak Value	Mean Value	Standard Deviation	Root-Mean Square
ILL #6	1	0.088	-37.2	-4.7	5.5	-7.2
IS	1	0.105	-23.1	-1.5	2.6	-2.7

ILL #6 - Illinois #6 coal; IS - Illinois Shale-type material.

2.1 LCA OPERATIONAL DESCRIPTION

The linear cutting apparatus (LCA), shown in figure 1, was designed to perform a linear cut in a coal sample block under controlled laboratory conditions. The system consists of two basic components--the coal sample carriage (foreground) and the counterbalance carriage (background)--and employs the force of gravity to provide relative motion between the sample carriage and the cutting tool. The LCA provides both the capability of variable depth of cut (approximately 0 to 2 inches) and variable cutting speed (approximately 5 to 105 ips). The cutting speed is controlled by the selection of a given drop height along with a specific counterbalance loading. The sample carriage accelerates under gravity until the cutting tool enters the coal sample. Once the cutting force has reached the level of the counterbalance loading, the sample carriage will no longer accelerate, and the sample carriage velocity will remain constant.

For the LCA experiments conducted during this program, the LCA was operated at its upper limit to provide the fastest possible cutting speeds. This upper limit was accomplished by using a maximum allowable drop height of approximately 50 inches, with zero counterbalance loading. This configuration provided an average cutting speed of approximately 105 ips, as shown in figure 2. The depth of cut was set to either 0.5 or 1.0 inches, depending upon the specific experiment being conducted.

2.2 DEVELOPMENT OF AN INSTRUMENTED LONGWALL CUTTING TOOL FOR LCA EXPERIMENTS

Since the cutting experiments to be conducted using the LCA were to encompass a variety of materials of which an upper bound of the cutting forces was unknown, it was anticipated

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

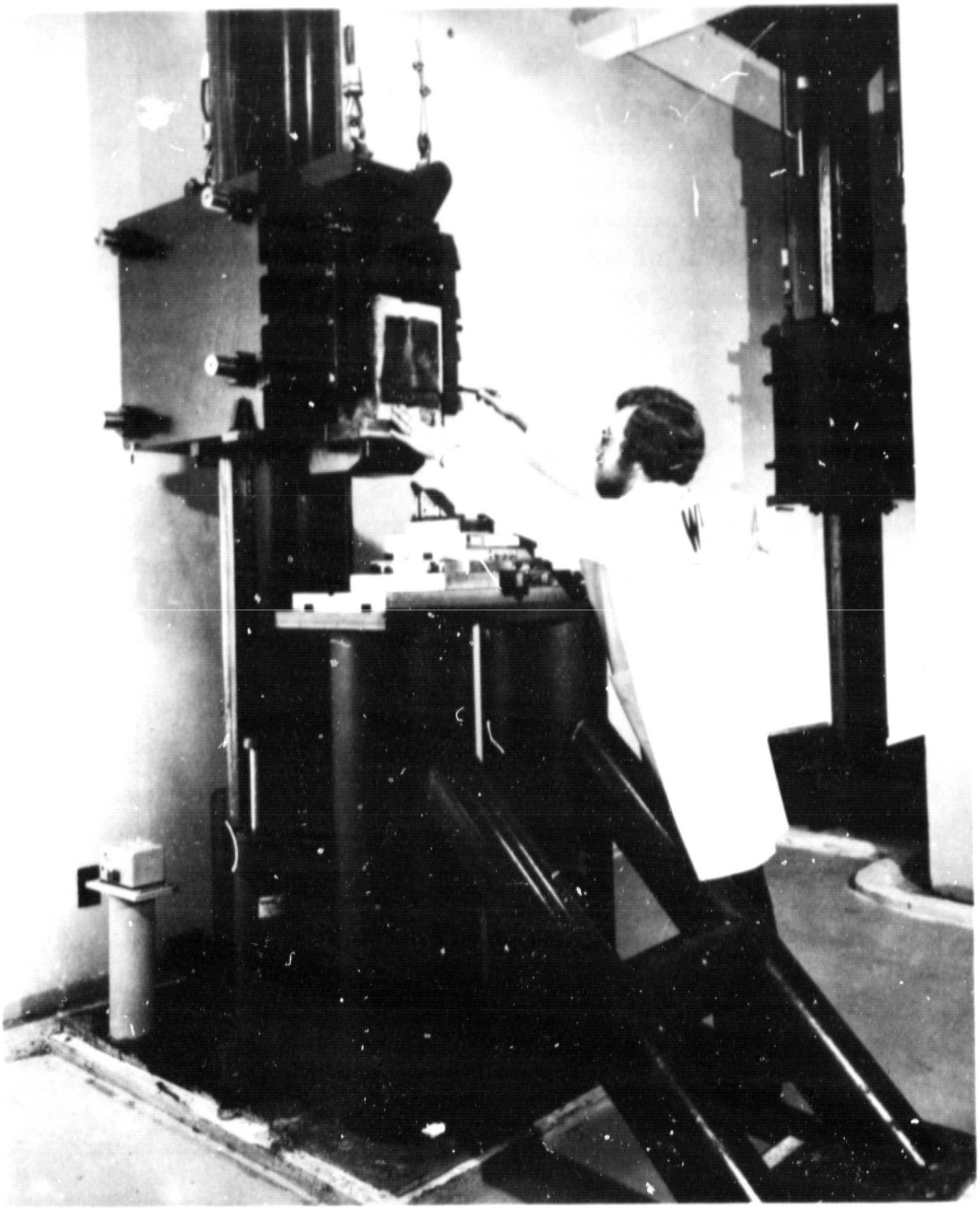


Figure 1. Linear Cutting Apparatus (LCA)

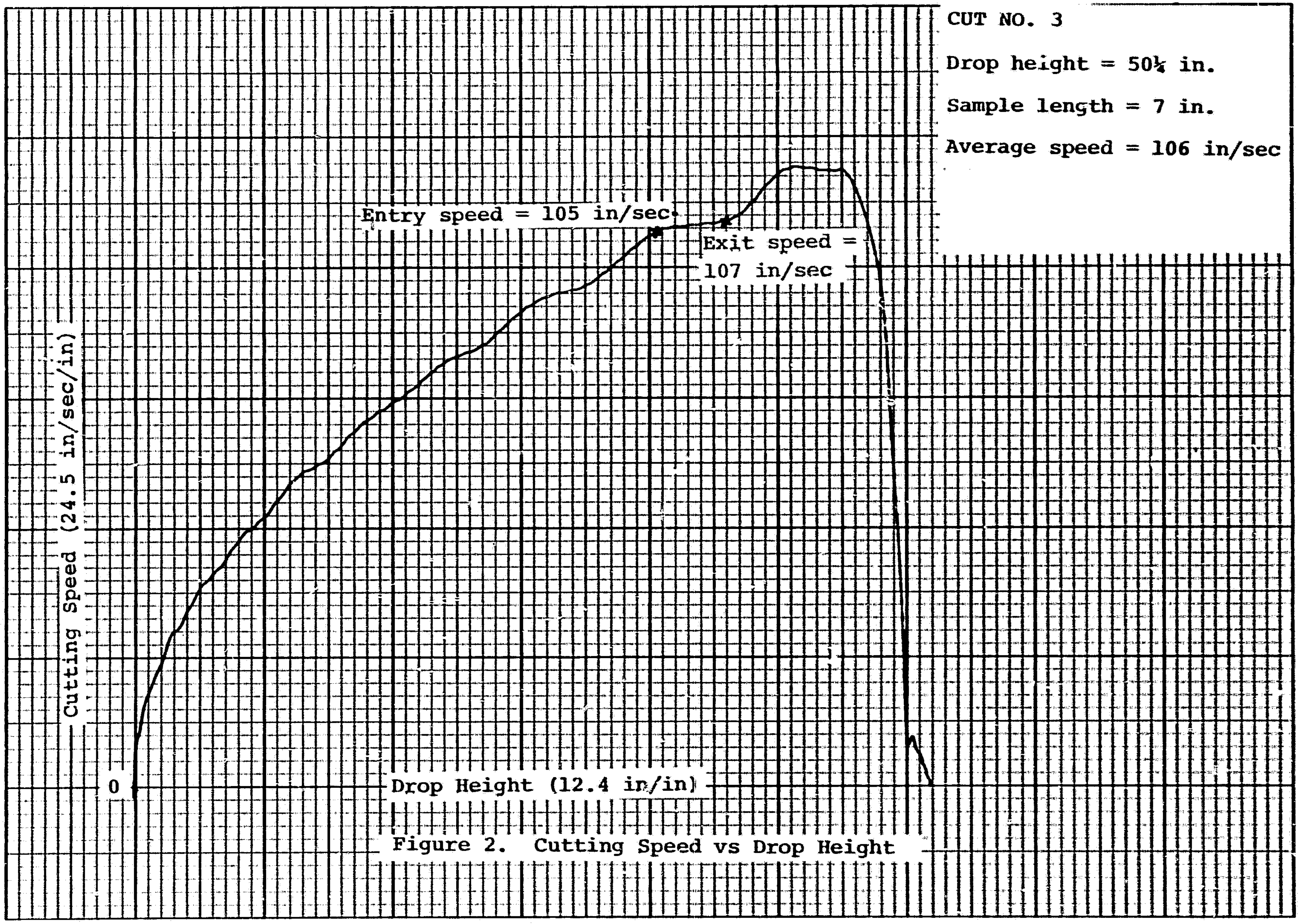
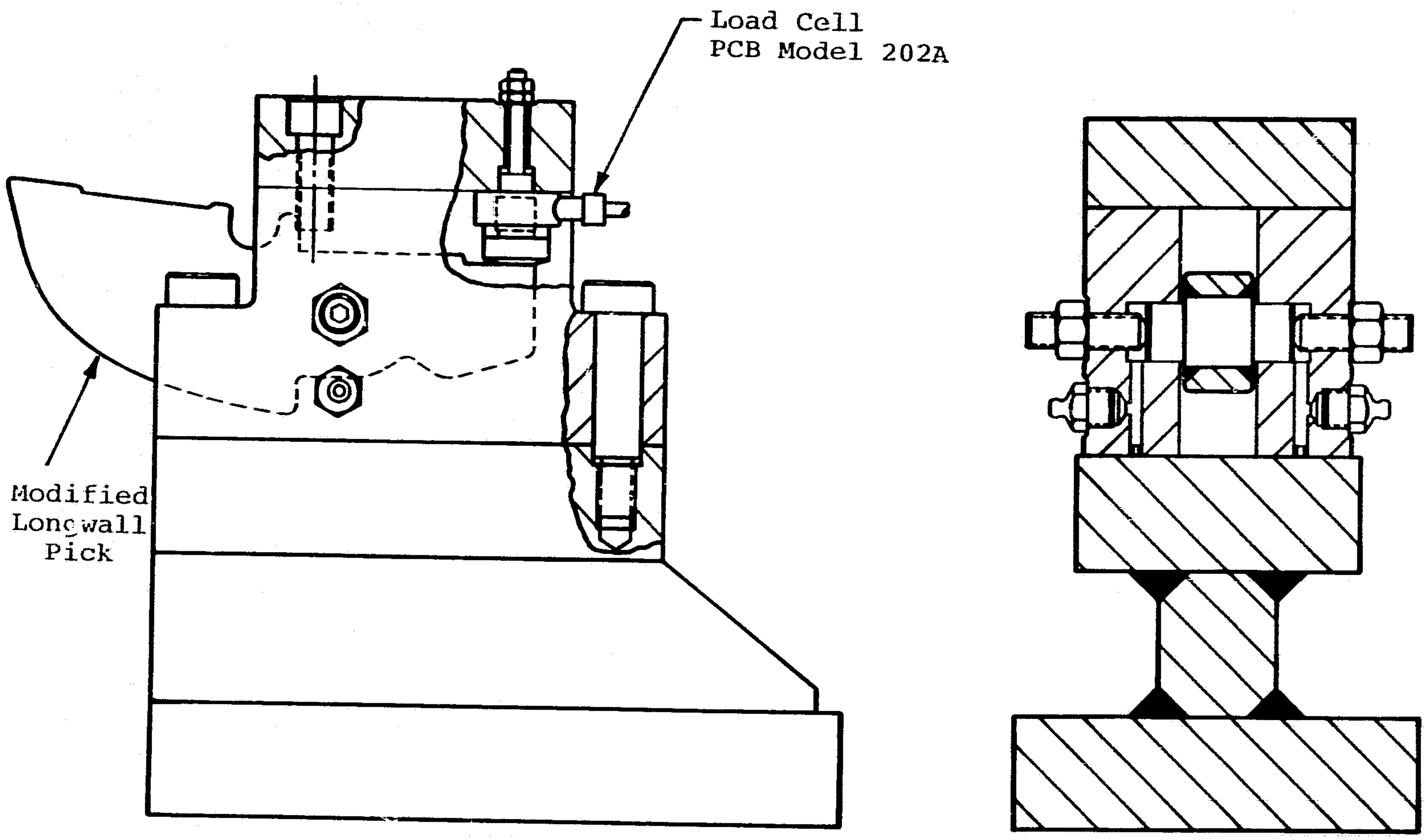


Figure 2. Cutting Speed vs Drop Height

that forces beyond the safe operational limits of a standard three-component force dynamometer, normally used with the LCA, would be encountered. As a result, an instrumented longwall cutting tool was designed and constructed. The cutting tool basically consisted of a conventional longwall mining pick and a quartz piezoelectric load cell arranged about a pivot point in such a manner as to transfer the cutting forces exerted on the tip of the pick to the load cell (PCB model 202A) mounted at the end of the pick shank (see figure 3). In order to minimize losses about the pivot point, extreme care was taken to design the pivot pin and holding blocks to minimize any lateral motion, which could degrade the force measurement.

Once the single-axis instrumented longwall cutting tool was built, a series of cutting tests were conducted simultaneously utilizing both the standard three-component dynamometer and the new instrumented pick. The two independent measuring devices were found to be in very good agreement, as evidenced by the data given in figures 4 and 5, respectively. The instrumented longwall cutting tool performed satisfactorly during the early phases of the program; however, the longwall pick was broken during an attempt to make a one-inch-deep cut in Illinois shale-type material (cut 63). Photographs of the broken pick are displayed in figure 6. Note that the pick failed in the general vicinity of the pivot pin. This failure is believed to be attributable to the fact that the strength of the shank material was reduced when the pivot pin was welded in place. To correct the problem, a second pick was constructed with the shank/pivot region reinforced (see figure 7). In addition, the pick was heat-treated to a hardness of at least Rockwell C-32. It was felt that the additional reinforcement of the pivot area and the heat treatment would strengthen the pick and remove any areas of high stress concentration that may



a) Side View

b) End View

Figure 3. Instrumented Longwall Pick Assembly

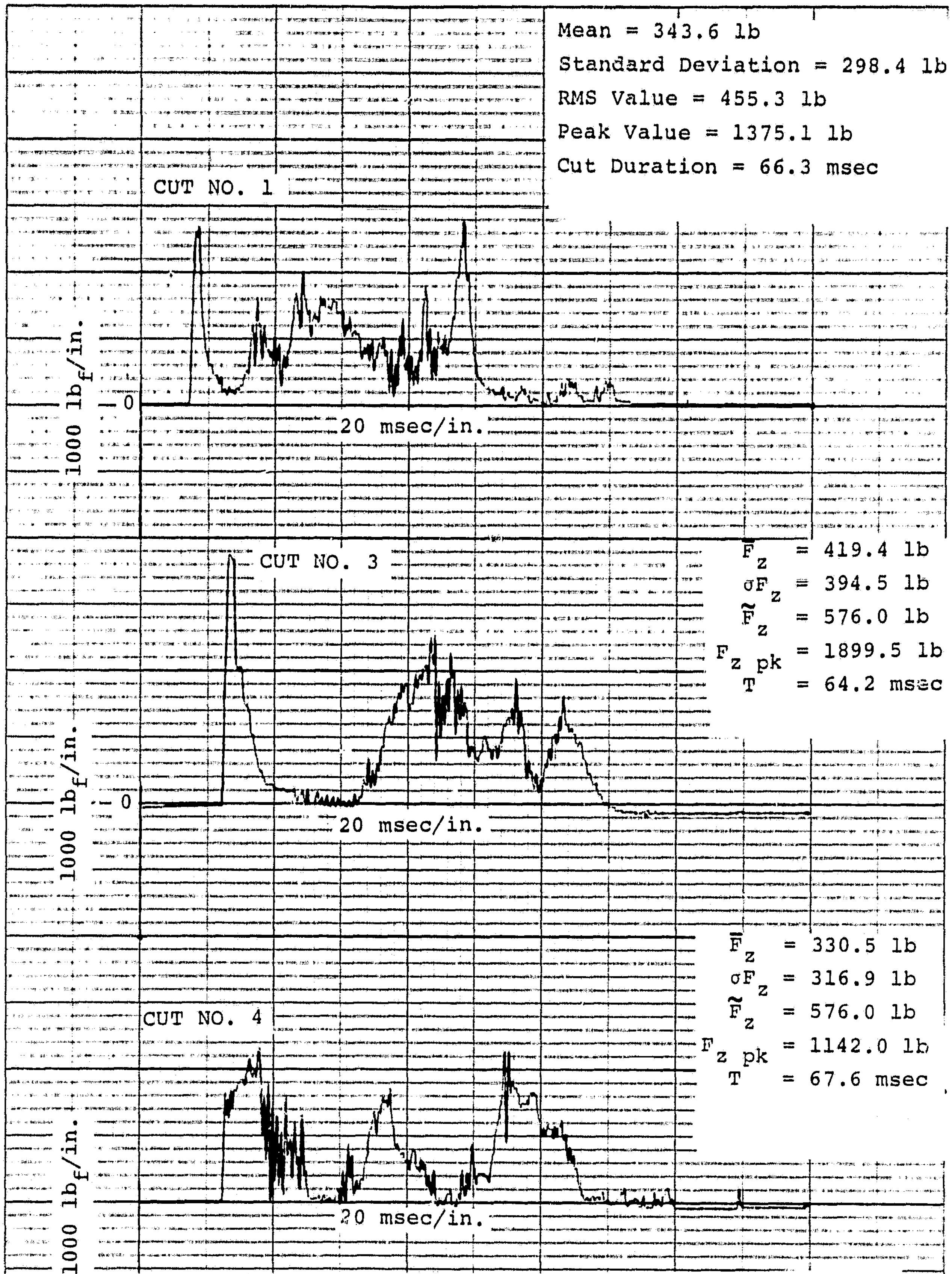


Figure 4. Force Time Histories and Cutting Force Results for Instrumented Longwall Pick

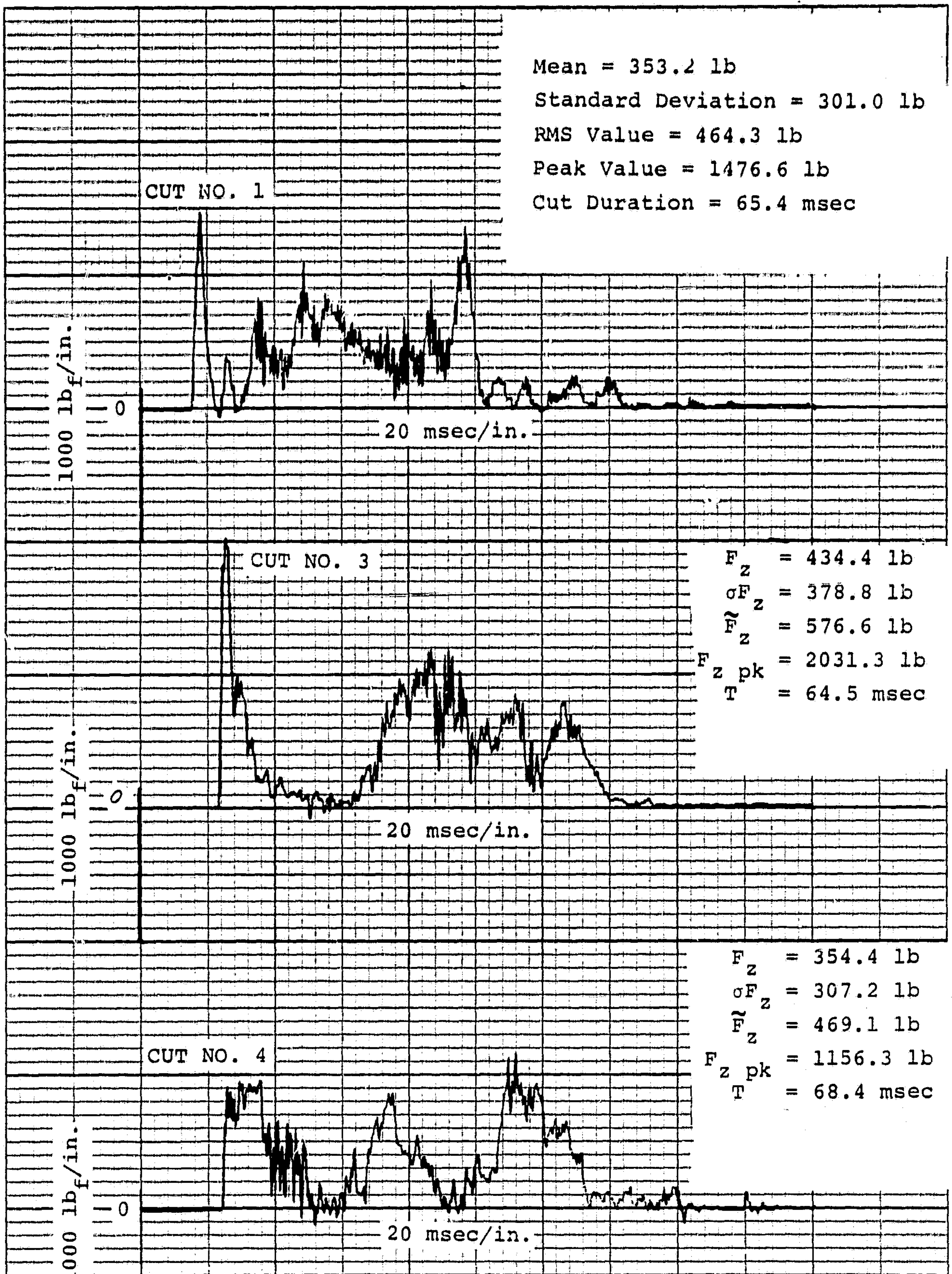
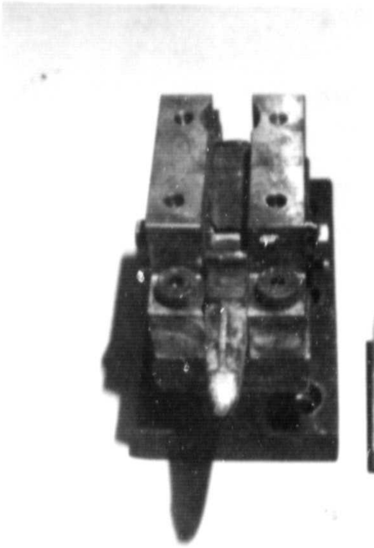
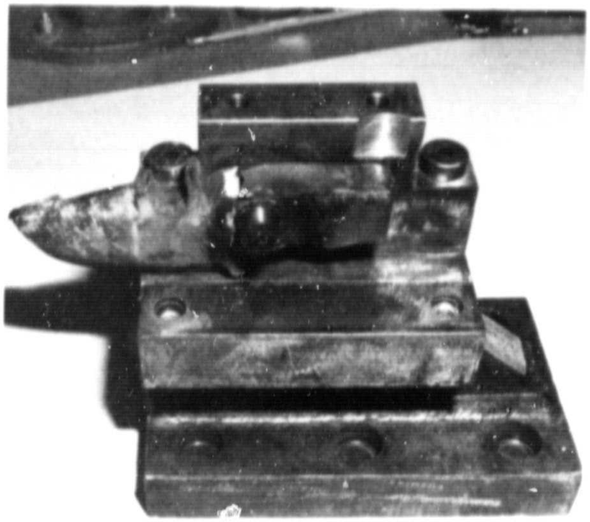


Figure 5. Force Time Histories and Cutting Force Results for Three-Component Dynamometer



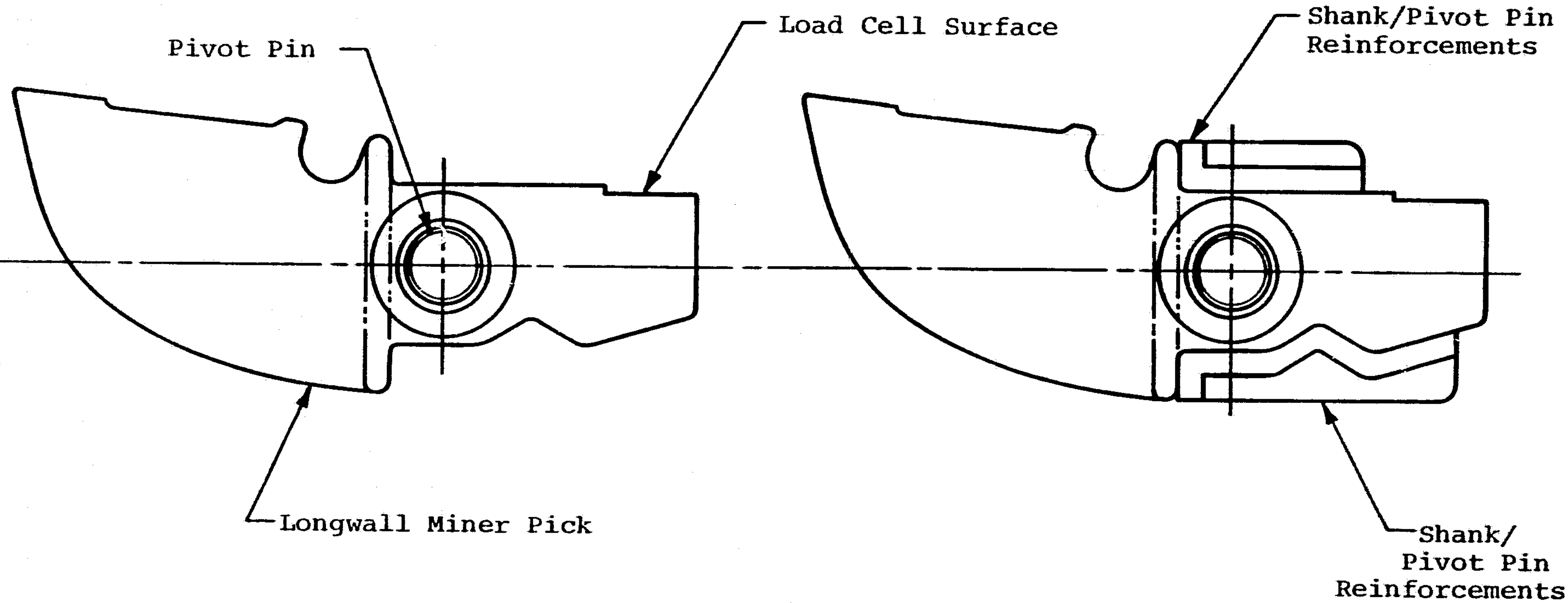
a) Top Plate Removed



b) Side Plate Removed

c) Pick Removed

Figure 6. Broken Longwall Pick Assembly



a) Original Modified Longwall Pick

b) Reinforced Modified Longwall Pick

Figure 7. Longwall Cutting Pick Modifications

have been caused by the insertion and welding of the pivot pin in place. The improved longwall cutting tool assembly shown in figure 8 was utilized, and functioned satisfactorily, for the remainder of the LCA cutting experiments.

2.3 BRUCETON SYNTHETIC COAL/SHALE CUTTING FORCE RESULTS

The initial phase of the cutting experiments required collection of synthetic coal/shale materials from the first artificial coal seam constructed at DOE's mock longwall test facility in Bruceton, Pennsylvania. A total of forty cuts were performed on these materials and are outlined as follows:

- Ten 1/2-inch cuts in Bruceton Synthetic Coal (BSC)
- Ten 1-inch cuts in Bruceton Synthetic Coal (BSC)
- Ten 1/2-inch cuts in Bruceton Synthetic Shale (BSS)
- Ten 1-inch cuts in Bruceton Synthetic Shale (BSS)

On the basis of the information given in table 1, a sample-average mean cutting force of approximately 300 lb_f was incurred for a 1/2-inch depth of cut in Bruceton synthetic coal, while a one-inch depth of cut in the same material required approximately 800 lb_f. The Bruceton synthetic roof-shale material displayed sample-average cutting forces on the order of 600 lb_f and 1700 lb_f for a 1/2-inch and one-inch deep cut, respectively. The sample-average standard deviations reflect the same behavior as those of real coal [1]. Figure 9 contains before-and-after photographs of typical cuts in the Bruceton synthetic coal and shale.

2.4 ILLINOIS #6 COAL/ROOF SHALE-TYPE MATERIAL CUTTING FORCE RESULTS

At the outset of the program, the coal and roof shale materials to be utilized for LCA experiments were to be supplied and obtained by NASA from the Old Ben Mine near Benton,

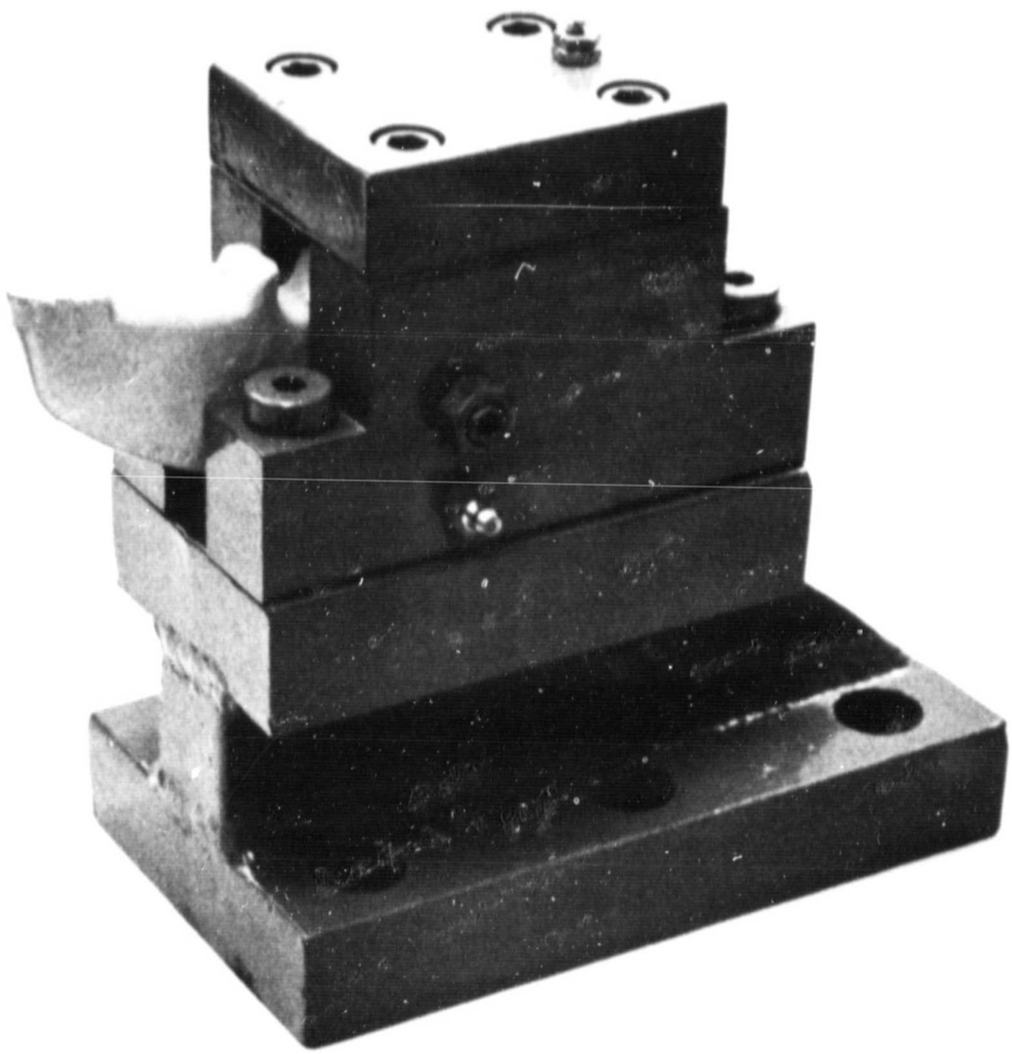
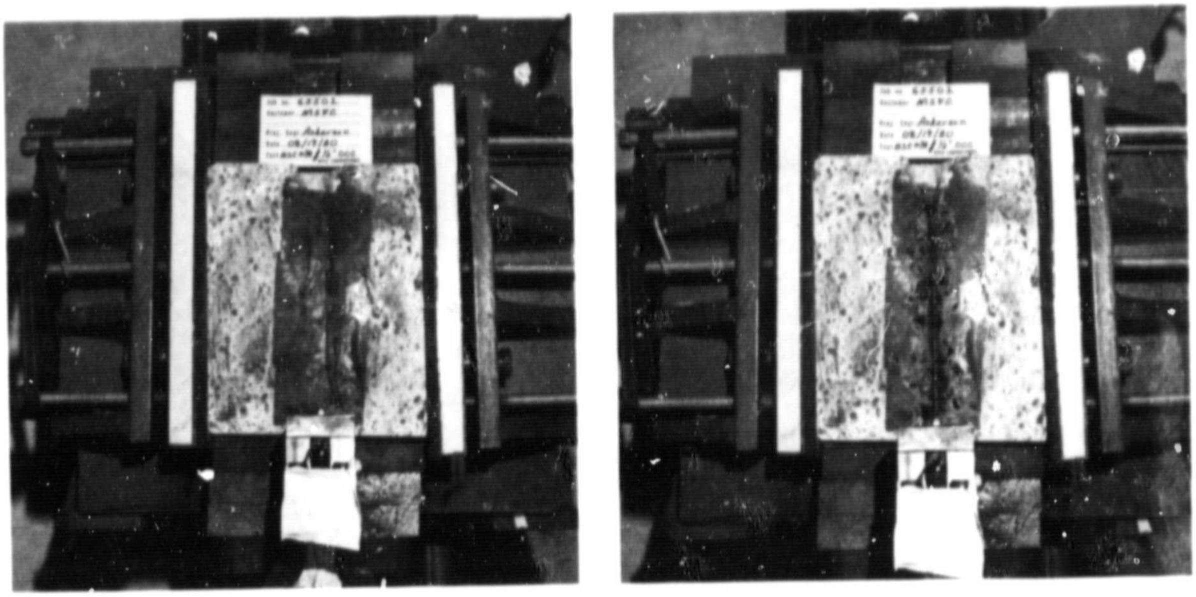
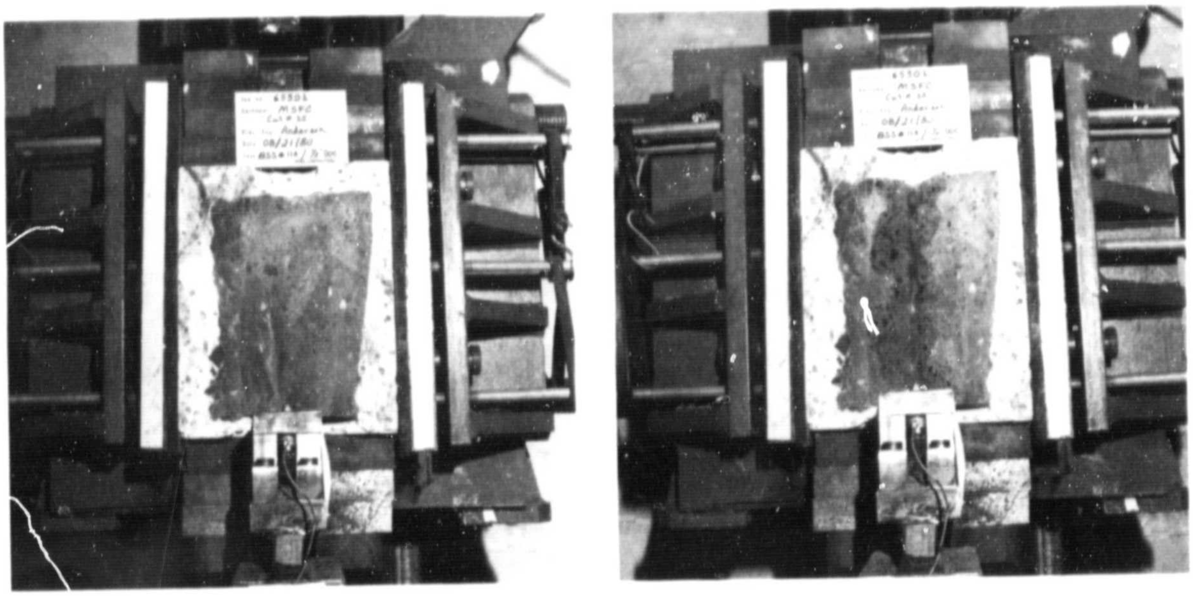


Figure 8. Instrumented Longwall Pick Assembly for LCA Laboratory Use



a) 1/2-Inch Depth of Cut on Bruceton Synthetic Coal



Before After

b) 1/1-Inch Depth of Cut on Bruceton Synthetic Shale

Figure 9. Before-and-After Photographs of Typical LCA Cuts Performed on Bruceton Synthetic Coal and Shale

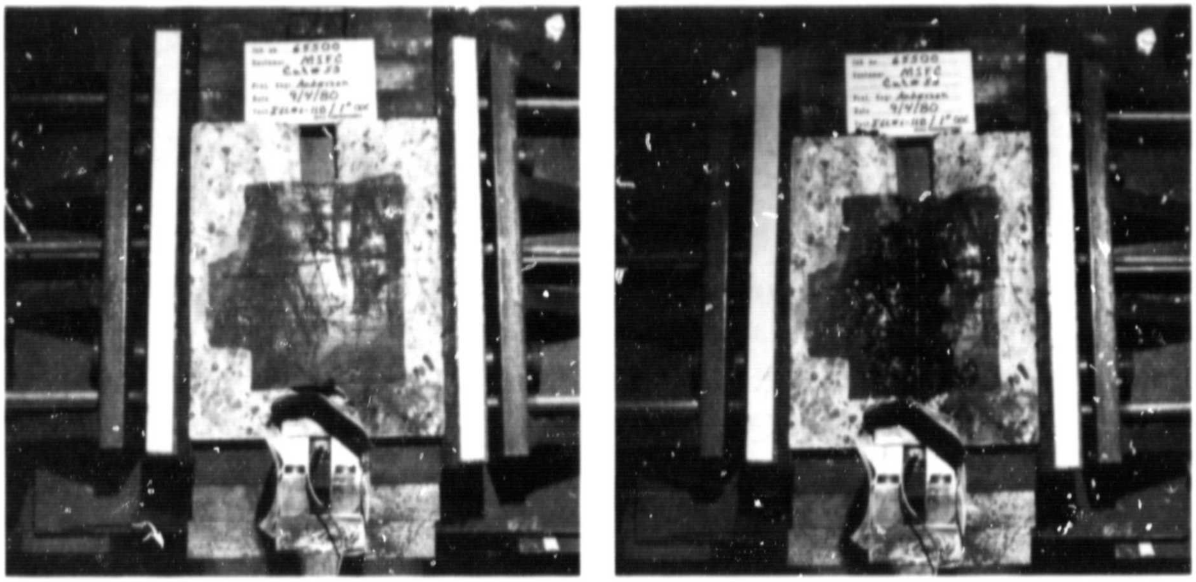
Illinois. In the interest of expediting the performance of the specified testing, NASA requested Wyle's assistance in procuring the required material. It was determined that the coal seam being mined at Old Ben was the Illinois #6 coal seam. Wyle was able to locate a surface mine in Illinois where the Illinois #6 seam coal was being mined. With the cooperation of the Peabody Coal Company, and with the approval of the C.O.R., Wyle obtained test samples from a surface mine in the Illinois #6 seam. The coal samples obtained are felt to be representative of that found in the Old Ben Mine. The similarity of the overburden material to that of the roof at Old Ben was unknown, however, and the shale-type material could only, at best, be considered as typical roof material.

Twenty-nine cuts were performed on the Illinois coal/shale-type materials and are outlined as follows:

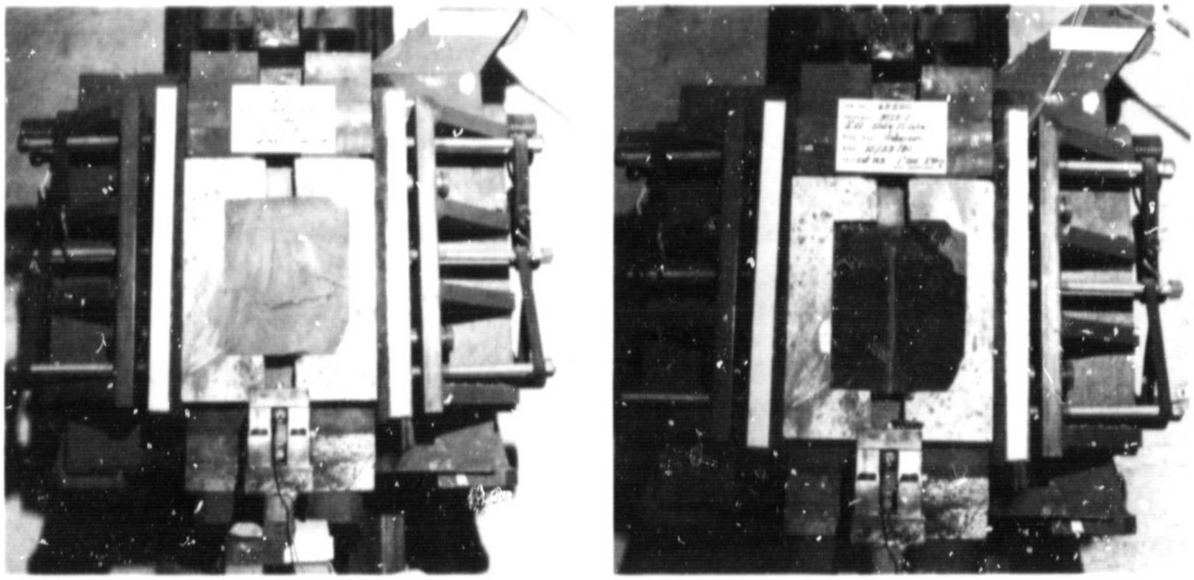
- Ten 1-inch cuts in Illinois #6 coal (ILL #6)
- Ten 1/2-inch cuts in Illinois Shale-type material (IS)
- Nine 1-inch cuts in Illinois Shale-type material (IS)

Because the instrumented pick was broken on cut 63, the total number of cuts was one short of the recommended thirty. No data could be obtained from this cut, and the limited quantity of shale-type samples required its deletion. Figure 10 contains before-and-after photographs for typical cuts in Illinois coal and shale-type materials.

On the basis of the results given in table 1, the LCA cutting experiments showed that an average cutting force of approximately 600 pounds could be expected when cutting Illinois #6 coal at a one-inch depth of cut. On the other hand, a one-inch-deep cut through Illinois shale-type material required an average cutting force of approximately 900



a) One-Inch Depth of Cut on Illinois #6 Coal



Before After

b) One-Inch Depth of Cut on Illinois Shale-Type Material

Figure 10. Before-and-After Photographs of Typical LCA Cuts Performed on Illinois #6 Coal and Shale-Type Material

pounds. The sample-averaged standard deviations, or the average variation in cutting force, for these one-inch-deep cuts in coal and shale-type material were on the order of 500 pounds for the coal and 700 pounds for the shale-type material. With these large standard deviations in mind, it appeared that either a sample population of ten cuts in each material was not sufficient to approach the true mean value of the cutting force or that a large deviation about the mean is inherently fundamental to the fracture process. Based upon previous cutting research, a large deviation about the mean cutting force has been observed and is considered to be fundamental to the fracture process for coal [1, 2, 3].

Inspection of the individual cut results in appendix A pointed out the existance of an extremely wide range of the mean cutting force for both 1/2-inch and 1-inch cuts in Illinois shale-type material. After the first few cutting experiments using the shale-type samples were completed, it became evident that two kinds of shale-type material (possibly shale and slate) has been obtained. Visual inspection of the samples failed to be effective in identifying the different materials. As a result, no attempts were made to discriminate between the two kinds of material prior to the continuation of the LCA cutting experiments. Hardness tests, performed later by NASA personnel using a Shore durometer hardness test device (type D), indicated similar results. It should be pointed out, however, that these materials were being considered, at best, typical overburden materials.

Section 3

SYNTHETIC COAL/ROOF-SHALE FORMULAE INVESTIGATION

To effectively perform above-ground experimental research on underground mining machines, it is necessary to provide some type of material that can be utilized as a substitute for the underground coal seam during cutting experiments. In general, this material should exhibit the following characteristics:

- Can be constructed from readily available and inexpensive ingredients.
- Can be cast into a large block without internal reinforcement.
- Can provide cutting force characteristics similar to those of real coal/roof material.

Several synthetic, or artificial, coal seams have been cast and utilized for testing purposes. The materials used range from those of commercially available concrete to special formulations of various ingredients. As of this writing, two synthetic coal seams have been cast at Wyle's Huntsville facility, and at least two seams have been cast at DOE's mock longwall test facility at Bruceton, Pennsylvania. Concern about the similarity of the cutting forces associated with the first Bruceton synthetic seam to those of real materials have led to the need to expand on the formulation utilized.

Task 2 of the present contract required further experimentation to develop a formula that best simulated the cutting force characteristics of Old Ben coal/roof shale. Evaluation of the existing synthetic materials from the first Bruceton seam were conducted during the phase 1 LCA cutting

experiments. No less than five formulations for synthetic coal/roof shale were developed and a second phase of LCA cutting experiments was conducted to quantify the forces required to cut each. Again, to provide reasonable statistical accuracy, ten cuts in each formula were performed.

3.1 INGREDIENTS FOR TRIAL SYNTHETIC COAL FORMULAE (SCF)

Both the Wyle and DOE synthetic coal seams mentioned earlier were based on a formula requiring a given number of parts of a specific ingredient to be mixed by volume. The first DOE seam was constructed using the formulation given in the first entry of table 3. In general, the accepted ingredients, which have given reasonable results in the past, are (1) coal, (2) bottom ash, (3) Portland cement, and (4) water (with water being the least controlled ingredient).

The synthetic formulations developed for experimentation retained these same basic ingredients with the exception that two types of cement were used. Wyle's experience with

TABLE 3. SYNTHETIC FORMULATIONS

	Ingredients to be Mixed by Volume			
Formula Designation	Coal[1] (parts)	Bottom Ash[2] (parts)	Cement (parts)	Water[3] (parts)
DOE (first seam)	5	4	½	--
SCF (5/4/½)	5	4	½	--
SCF (5/4/1)	5	4	1	--
SCF (5/4/1½)	5	4	1½	--
SCF (5/4/2)	5	4	2	--
SCF (5/2½/2)	5	2½	2	--
SCF (5/3½/1)	5	3½	1	--
SCF (5/3/1½)	5	3	1½	--

NOTES: 1. Coal size not to be greater than 2 inches in diameter.
2. No clinkers.
3. Water to be determined by experiment.

a gypsum-based cement (Hydrostone) used to encapsulate coal in the preparation of samples for LCA experiments had shown that Hydrostone characteristically cured rapidly and provided a very hard material (relative to Portland cement formulations). With this in mind, six formulations--in addition to the DOE formula--were mixed, first, utilizing gypsum-based cement (Hydrostone) and, second, Portland cement.

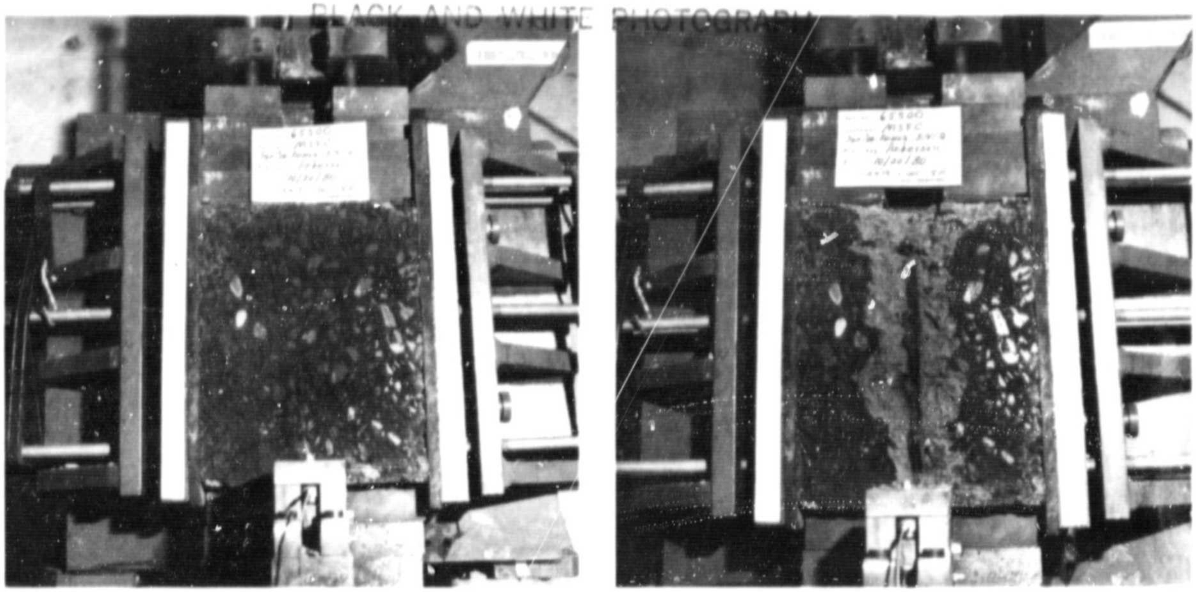
The ingredients necessary to prepare the sample were procured from various sources: "Stoker grade" (less than 2-inch diameter) was obtained from a local coal yard; the bottom ash was collected at TVA's Widow Creek steam plant; and Portland cement was purchased from a local building supply company. All the sample blocks cast using Portland cement cured to-the-touch approximately four hours after pouring; however the sample blocks cast using Hydrostone inexplicably failed to cure to a state suitable for their use as samples. As a result, no cuts were made using the gypsum-based cement synthetic coal/shale samples. The Portland cement samples were allowed to cure for approximately 18 days prior to conducting cutting experiments.

3.2 SYNTHETIC COAL FORMULAE CUTTING FORCE RESULTS

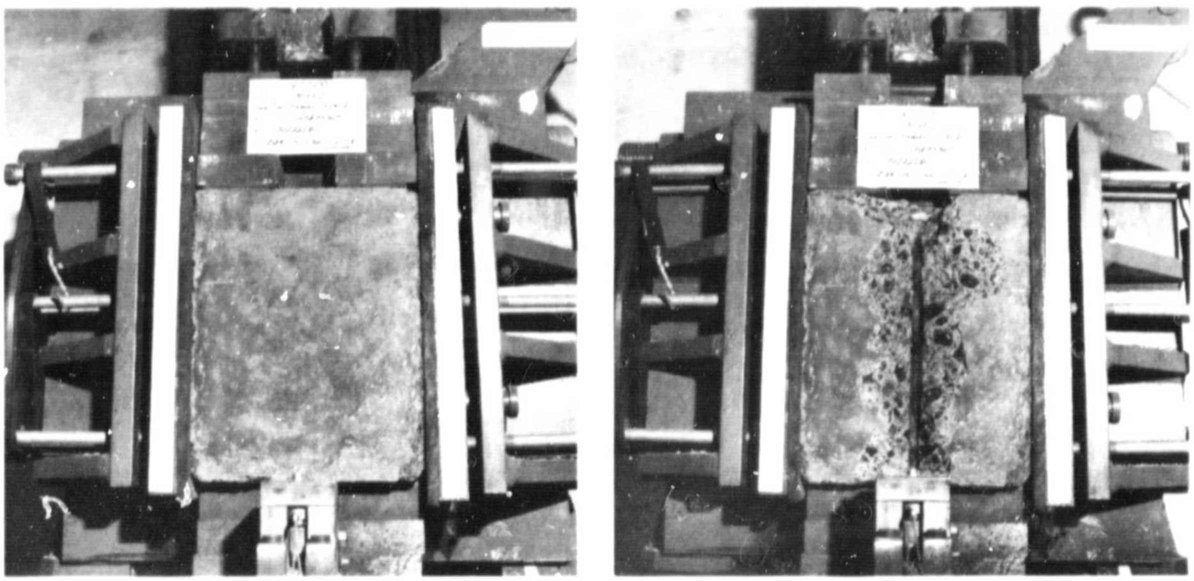
All the phase 2 LCA cutting experiments were performed at a cutting speed of approximately 105 ips and at a one-inch depth of cut. The data was reduced as before, and the individual cut results have been included in appendix A, table A1. The sample-averaged statistical quantities are shown in table 1 for easy comparison with other materials.

Samples of the original DOE formula were cast to provide a control group, which would allow a comparison between the DOE and Wyle-prepared sample of the same formula. The large differential in the sample-averaged cutting force of the

control (phase 1-BSC) was not surprising since past experience with the development of synthetic coal seams at Wyle have yielded similar results. Apparently, when a test case formula is scaled up to allow the construction of a very large seam, the lack of control that can be placed on the mixing process results in an upward shift in the cutting force characteristics. In addition, it is not known to what extent a long curing time has on the synthetic samples. Of all the ingredients utilized in the preparation of the synthetic samples, cement was expected to be the one ingredient that would provide the greatest change in cutting force. Therefore, in order to determine the effect of the addition of cement to the formula, the number of parts of cement was increased. The sample-average mean cutting force increased by approximately 200 lb_f for each additional half part of cement over a range of 400 to 1200 lb_f. Figure 11 contains before-and-after photographs of typical synthetic coal/shale material.



a) One-Inch Depth of Cut in SCF (5/4/½)



Before After

b) One-Inch Depth of Cut in SCF (5/4/2)

Figure 11. Before-and-After Photographs of Typical LCA Cuts Performed on Synthetic Coal/Shale Samples

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Section 4

SENSITIZED PICK FEASIBILITY STUDY (CONCEPTUAL DEFINITION)

During the longwall mining process, the shearing machine traverses the length of the coal seam, and the vertical position of the forward and rear cutting drums are manually controlled by the operator. Since the vertical height of the coal seam may vary significantly over the length of the seam, it is very difficult, if not impossible, for the operator to follow the coal seam/floor/roof boundary. As a result, the cutting drum can deviate from the ideal path (along the boundary), either cutting into the roof/floor, and thereby contaminating the mined coal with roof/floor material, or leaving an excess of coal unmined, thus impacting coal production. Additionally, cutting into the roof/floor material produces increased bit wear and promotes premature failure of mechanical systems, which could result in additional machine repairs and downtime to effect these repairs. In order to improve the ability of the operator to control the cutting drums, and to provide the operator with information as to whether the drum is cutting into coal or roof/floor material, it was proposed that a special pick (sensitized pick) be placed on the cutting drum. As a third task of the present program, laboratory investigation and LCA cutting experiments were to be performed to provide insight into the feasibility of developing such a device.

4.1 SYSTEM REQUIREMENTS AND COMPONENTS

The sensitized pick system requirements can be listed as follows:

- The pick assembly to be placed on the drum should fit within the confines of the sensitized pick block presently being used on the Joy shearer at Bruceton, Pennsylvania.

- The pick assembly should incorporate a piezoelectric crystal capable of supplying at least 100 volts without exceeding the elastic limit of the crystal.

- The system should be self-powered, that is, no external power sources other than the piezoelectric crystal itself would be allowed.

- The information required to discriminate between cutting coal and roof material must be transmitted to the operator's station from the rotating drum.

In essence, the sensitized pick concept can best be summarized as the addition of a self-powered, radiating, instrumented pick capable of discriminating between the coal and roof material on the basis of cutting force and then relaying the information to the operator. The concept relies upon the fundamental premise that the force required to cut through roof material would be substantially different from the force required to cut through coal for a given depth of cut. It is further assumed that the force required to cut roof material would be much greater than the force required to cut coal.

Since the validity of these two assumptions was in question, it was felt that before any relevant work could be performed to determine the feasibility of such a concept, the phase 1 LCA cutting experiments should be completed. However, in view of the amount of time required to prepare for and complete these experiments, these assumptions were tentatively accepted as correct, and work was begun to identify and procure a candidate piezoelectric transducer.

4.1.1 PIEZOELECTRIC TRANSDUCER/SENSOR

Since no data was available to identify an upper bound for the forces that might be expected from cutting roof shale-type materials, a reasonable safety factor for design purposes was assumed and applied to known information concerning the peak cutting forces that had been experienced during previous cutting experiments conducted using real coal. Peak forces on the order of 5000 lb_f had been previously encountered during these experiments performed at a one-inch depth of cut. Based upon this information, and the assumption that the force required to cut roof shale-type material would be significantly larger than that for coal, an upper force limit of 15,000 lb_f was determined (safety factor of three).

After some investigation into the possibility of acquiring and utilizing some type of raw piezoelectric material, it became clear that it would be advantageous to utilize an off-the-shelf load cell, if one could be identified. As a result, a load cell with a nominal operational range of 10,000 lb_f (15,000 lb_f maximum) was identified and procured from PCB Piezoelectronics. The manufacturer's specifications for the selected load cell (PCB model 212A) are given in table 4. For the nominal charge sensitivity and internal capacitance given in table 4, the theoretical voltage output sensitivity was calculated to be one volt/lb_f; however, the specific values (given in parentheses in table 4) associated with the particular transducer supplied reduced the voltage output sensitivity to approximately 0.625 volts/lb_f. These theoretically calculated values of the output sensitivity are based upon a perfectly matched output/input impedance conditions. The actual output voltage sensitivity can be calculated using the following equation [4]:

$$V_o = \frac{q}{C_q + C_c + C_i}, \qquad (1)$$

where V_o is the output voltage per lb_f input,

q is the charge sensitivity of the load cell,

C_q is the internal capacitance of the load cell,

C_c is the total capacitance of the output cabling,

and C_i is the input capacitance of the next stage (transmitter circuit).

As can be seen, the more capacitance associated with the circuit being driven by the load cell, the lower the output voltage becomes for a given input. As long as the magnitude of the cutting force is substantial, however, the targeted 100-volt peak level was considered achievable. Laboratory experiments were conducted on the candidate load cell to quantify its response, and the results of these experiments will be presented later in the report.

TABLE 4. SENSITIZED PICK LOAD CELL SPECIFICATION (PCB Model 212A)

General Specifications	Value or Range
Load Range, lb_f	10,000 (15,000 maximum)
Linearity, %	1
Insulation Resistance, ohms	10^{12}
Temperature Coefficient, %/^oF	0.01
Temperature Range, ^oF	-400 to +500
Vibration/Shock, g	2,000/10,000
Sensing Element	Quartz
Case Material	Stainless steel
Connector	Micro 10-32
Output Polarity	Negative
Nominal Sensitivity, pc/lb	20 (12.0)
Nominal Capacitance, pF	20 (19.2)

4.1.2 DATA TRANSMISSION CIRCUIT AND RECEIVER

Since one of the system requirements for the sensitized pick was that external power sources would not be allowed, it was clear that some sort of power storage device would be necessary, especially with the piezoelectric load cell under load for only half the drum rotational cycle. Even more critical was the fact that under normal circumstances the sensitized pick would be only in contact with the roof/floor material for a very small fraction of the drum rotational cycle, and the output of the load cell would be maximum only during this short period. Since the voltage output of the load cell was greater by far than the current output, a capacitor would be required to store all the energy produced during the cutting half cycle of the drum rotation.

The transmitter circuit diagram is shown in figure 12. The basic operational characteristics of the circuit can be outlined as follows:

- The voltage supplied by the piezoelectric load cell is stored in a capacitor during the cutting half cycle of the drum rotation. The voltage developed across the terminals of the capacitor is approximately equal to the root-mean-square value of the output of the load cell.

- When the pick is cutting through the roof material, the output voltage developed by the load cell is assumed to be greater than when simply cutting coal since the cutting forces should be greater.

- A pulse train of short-duration pulses is generated once a voltage threshold level is reached. The pulse repetition frequency is proportional to the voltage across the capacitor.

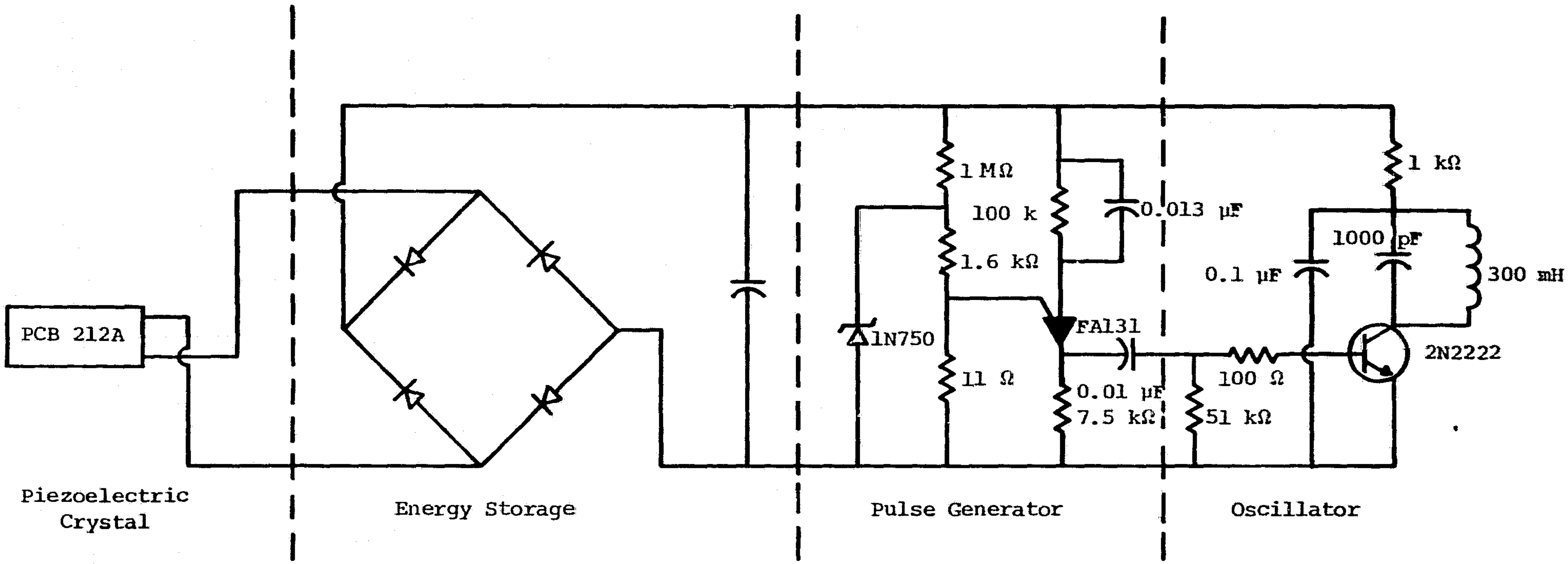


Figure 12. Prototype Data Transmission Circuit

- The pulses are fed into a transistor oscillator stage, which is tuned to oscillate at approximately 700 kHz. Each pulse activates the transistor oscillator stage, which radiates at the tuned frequency for the duration of the pulse, and the inductance coil is utilized as a ferrite antenna.

- The radiation is received by a typical AM radio receiver tuned to approximately 700 kHz.

The threshold at which the first pulses are generated can be utilized as a discriminator between coal and roof material. However, this would tend to limit the usefulness of the circuit by merely having a binary-type indication (cutting coal or cutting roof material). On the other hand, the radiated signal is received at the same repetition frequency as the pulse train. These pulses could be counted over a given period of time to yield an indication as to the magnitude of the cutting forces being measured--the higher the count, the larger the cutting force.

4.2 LABORATORY INVESTIGATIONS AND LCA EXPERIMENTATION

To determine the operational characteristics of the candidate piezoelectric transducer and the prototype transmitter, a variety of laboratory experiments were performed on each; and, finally, LCA cutting experiments were performed using a modified version of the laboratory longwall instrumented pick as a prototype sensitized pick.

The PCB model 212A piezoelectric load cell was rigidly mounted to a reaction mass in the laboratory and struck with an instrumented hammer. The output of both the hammer and the model 212A were captured using the Norland 2001A digital waveform analyzer. The mass of the reaction mass was very

large with respect to the mass of the hammer; and, therefore, the force exerted on the two load cells at impact was approximately equal. This experiment was repeated several times, and the output voltage of the model 212A load cell along with the input force was recorded. One experiment was conducted using a 25-foot, orange, microdot cable to connect the model 212A load cell to the monitoring device. A second experiment was performed with the model 212A load cell connected to the monitoring device through a five-foot, orange, microdot cable. The total capacitance of the 25-foot cable was measured to be 775 pF, and the total capacitance of the five-foot cable was measured to be 150 pF. The input capacitance of the Norland is 30 pF. Theoretical calculations using equation 1 predicted the voltage output sensitivity factor to be 14.6 mV/lb_f for the 25-foot cable and 66.6 mV/lb_f for the five-foot cable. A linear regression performed on the impact force test results yielded a value of 13.8 mV/lb_f for the 25-foot cable and 52.6 mV/lb_f for the five-foot cable, with coefficients of determination better than 0.9 for both cases.

With the model 212A load cell installed in the longwall instrumented cutting tool assembly, data from nine 1-inch-deep cuts in Illinois #6 coal and eight 1-inch-deep cuts in Illinois shale-type material was collected. The reduced data (output voltages) for each cut are shown in table A2 in appendix A, and the time histories for each cut are given in appendix B. For these LCA cutting experiments, the same 25-foot, orange, microdot cable utilized for the laboratory experiments was used to connect the load cell to the Norland 2001A waveform analyzer. The sample-averaged values for both sets of data has been displayed in table 2 to allow easy comparison with the sample averaged force values in table 1.

Experiments were performed in the laboratory on the prototype transmitter circuit. The circuit operated satisfactorily when powered by a variable dc voltage source as long as the voltage was set to at least eight volts. The transmitter drew a current of approximately one milliampere at an operational voltage of 10 volts and two milliamperes at an operational voltage of 20 volts, indicating an input resistance of approximately 10 kilohms.

Without an energy storage capacitor in the circuit, a one-hertz, 50% duty cycle, pulsed waveform was input to the circuit, and the circuit failed to operate. A capacitor was then placed across the input to the transmitter, and the circuit once again worked satisfactorily as long as the input voltage level was greater than eight volts. The 50% duty cycle pulsed waveform was considered to be a "best-case" simulation of the output of the load cell under actual mining conditions. A "worst-case" simulation of the actual mining conditions was considered to be a sharp, high, input level pulse on the order of five to 10 msec in duration. This would correspond to the short-lived contact of the sensitized pick and the roof material under actual mining conditions. With this type of input waveform the prototype transmitter circuit failed to operate.

Finally, the model 212A load cell was connected to the prototype circuit, and a series of impact forces were applied to the load cell with no response from the circuit. Logically, the next experiment to be attempted would have been to use the LCA to perform an actual cut in the two materials--coal and shale. Since samples of each material were in short supply, and in view of the worst-case experimental results, it was considered to be more advantageous to quantify the output voltage obtainable from the load cell than to attempt very risky experiments with both the load cell and transmitter.

The results of the output voltage LCA experiments are summarized in table 2, and individual results are given in table A2. In general, the magnitude output voltage was approximately twice as great for a 1-inch-deep cut in Illinois #6 coal as for the Illinois shale-type material. It should also be noted that the specific values will change if the cable length is changed. A cable length of less than one foot would be required for the present application and could result in much larger output voltages, provided the input capacitance and transducer capacitance remained constant.

Section 5

CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of the phase 1 coal cutting experiments, the Bruceton synthetic coal material was found to require slightly larger cutting force of the cutting tool than did the Illinois #6 coal. The 200 lb_f differential between the real coal and synthetic coal is a very small quantity when compared with the magnitude of the sample-averaged standard deviations associated with the experiments conducted. Therefore, the Bruceton synthetic coal is considered to be a reasonable substitute for real coal (Illinois #6 seam coal). In addition, the Bruceton synthetic shale material was found to exert a cutting force on the pick on the order of 2 to 2½ times greater than the force associated with the Bruceton synthetic coal, and these forces were approximately twice as great as those measured for Illinois shale-type material. Consequently, the Bruceton shale cannot be considered as a good substitute for the Illinois shale-type material. Nevertheless, this synthetic shale material can definitely be considered "harder" than its companion synthetic coal, Illinois #6, and the Illinois shale-type materials utilized for these experiments.

With respect to the Illinois #6 coal and the Illinois shale-type material, a sample-averaged differential of 300 lb_f is not considered to be a substantially large quantity in view of the sample-averaged standard deviation associated with the two cutting events. As a result, the general assumption that roof-shale materials would exert significantly greater cutting forces on the picks cannot be substantiated based on the materials utilized for these experiments. It should be pointed out, however, that the shale-type material utilized was obtained from the overburden of a surface mine and not

from an underground mine. Therefore, it is recommended that similar experiments be conducted on coal/roof material obtained from an underground mine.

The absolute feasibility of utilizing a sensitized pick on the longwall shearing drum cannot be determined from the results of the experiments that have been conducted. The results of the laboratory and LCA experiments on the various system components and available materials indicate that (1) a piezoelectric transducer or crystal cannot supply enough energy to power all system components, and (2) the determined force differential from the LCA cutting experiments is not substantial enough (even for a one-inch depth of cut) to assure accurate discrimination between coal and shale. As a result, the present sensitized pick concept is not feasible under apparent system constraints.

Of the synthetic coal formulae developed and subjected to LCA testing, SCF (5/4/½) exhibited a mean cutting force that correlated well to that of Illinois #6 coal, and SCF (5/5/1½) and SCF (5/2½/1) were the closest to the Illinois shale-type material.

REFERENCES

1. Becker, R. S., and G. R. Anderson, II. An Investigation of the Mechanics and Noise Associated with Coal Cutting. Wyle Laboratories Rept. WR 80-7, Feb. 15, 1980.

2. Evans, I., and C. D. Pomeroy. The Strength, Fracture and Workability of Coal. Pergamon Press, Oxford, England, 1966.

3. Roepke, W. W., D. P. Lindroth and T. A. Myren. Reduction of Dust and Energy During Coal Cutting Using Point Attack Bits. U. S. Bureau of Mines Rept. RI 8185, 1976.

4. Broch, J. T. Mechanical Vibration and Shock Measurements. B&K Instruments, Apr. 1976.

PRECEDING PAGE BLANK NOT FILMED

APPENDIX A

LCA CUTTING EXPERIMENTS DATA SUMMARY

APPENDIX A

LCA LABORATORY DATA SUMMARY

Contained in this appendix is a complete listing of the results of the LCA cutting experiments for each individual cut as well as each group. Table A1 presents the cutting force results, and Table A2 contains the results for the sensitized pick.

TABLE A1. LCA CUTTING FORCE RESULTS

Cut Number	Depth of Cut (in.)	Material Type	Cut Duration (sec)	Measured Cutting Force (lbf) Peak Value	Mean Value	Standard Deviation	Root-Mean Square
5	1/2	BSC	0.097	3566	382	418	567
6			0.098	1608	330	268	425
7			0.088	1911	316	303	438
9			0.103	2867	301	327	444
11			0.095	1876	322	372	492
17			0.095	1352	230	206	309
21			0.080	1503	241	269	361
22			0.075	1026	205	202	288
23			0.103	1247	321	252	409
24			0.092	1364	176	200	266
AVG	1/2	BSC	0.093	1832	282	290	400
8	1	BSC	0.102	2983	659	468	809
10			0.096	4778	959	791	1244
12			0.100	3356	881	576	1053
13			0.104	4195	685	565	889
14			0.102	4079	587	577	824
15			0.099	4568	928	677	1149
16			0.091	3566	733	564	925
18			0.098	2517	860	561	1028
19			0.085	1830	519	352	628
20			0.098	3123	896	617	1089
AVG	1	BSC	0.097	3500	771	585	964

BSC - Bruceton Synthetic Coal; BSS - Bruceton Synthetic Shale; ILL #6 - Illinois #6 Coal; IS - Illinois Shale-type Material; SCF - Synthetic Coal Formulation (Coal/Ash/Portland Cement).

Cut Number	Depth of Cut (in.)	Material Type	Cut Duration (sec)	Measured Cutting Force (lbf) Peak Value	Mean Value	Standard Deviation	Root-Mean Square
25	1/2	BSS	0.082	2820	579	473	748
27			0.104	3659	761	515	920
28			0.090	3566	894	560	1056
29			0.090	4195	880	646	1093
30			0.102	4172	792	509	942
31			0.096	2634	303	363	473
32			0.104	2774	340	388	517
33			0.091	3053	571	468	739
34			0.090	1655	239	268	360
35			0.099	3106	798	533	960
AVG	1/2	BSS	0.098	3163	616	472	781
26	1	BSS	0.099	5594	1594	953	1858
36			0.106	7031	2206	1126	2478
37			0.109	7422	2736	1418	3084
39			0.091	6641	1398	1015	1729
40			0.112	7227	1707	1113	2039
41			0.110	4932	1690	1089	2011
42			0.095	7422	1671	1063	1982
43			0.085	6397	1495	1083	1846
44			0.091	7617	1593	1268	2038
45			0.098	7520	1304	1068	1686
AVG	1	BSS	0.100	6780	1739	1127	2075

BSC - Bruceton Synthetic Coal; BSS - Bruceton Synthetic Shale; ILL #6 - Illinois #6 Coal; IS - Illinois Shale-type Material; SCF - Synthetic Coal Formulation (Coal/Ash/Portland Cement).

TABLE A1. LCA CUTTING FORCE RESULTS (Continued)

Cut Number	Depth of Cut (in.)	Material Type	Cut Duration (sec)	Measured Cutting Force (lbf)			
				Peak Value	Mean Value	Standard Deviation	Root-Mean Square
46	1	ILL #6	0.071	2217	667	443	801
47			0.081	4316	708	685	985
48			0.090	2063	348	285	450
49			0.084	4492	600	634	873
50			0.086	3015	568	508	762
51			0.083	1782	472	367	598
52			0.085	1477	381	352	519
53			0.071	2478	711	515	878
54			0.063	2488	596	514	787
55			0.072	3003	798	527	957
AVG	1	ILL #6	0.079	2733	585	497	761
56	1/2	IS	0.100	1240	290	223	366
58			0.088	854	184	159	243
59			0.079	688	344	137	370
60			0.111	4316	818	697	1071
61			0.089	2197	681	430	806
62			0.076	7520	1090	1092	1543
140			0.117	4520	600	563	823
141			0.091	6250	671	651	935
142			0.071	5110	840	804	1163
143			0.109	5818	808	765	1113
AVG	1/2	IS	0.092	3852	632	627	844

BSC - Bruceton Synthetic Coal; BSS - Bruceton Synthetic Shale; ILL #6 - Illinois #6 Coal; IS - Ilinois Shale-type Material; SCF - Synthetic Coal Formulation (Coal/Ash/Portland Cement).

Cut Number	Depth of Cut (in.)	Material Type	Cut Duration (sec)	Measured Cutting Force (lbf) Peak Value	Mean Value	Standard Deviation	Root-Mean Square
57	1	IS	0.100	1240	610	257	662
144			0.108	2437	745	535	918
145			0.086	2555	822	509	968
146			0.090	1887	786	484	924
147			0.115	904	276	197	340
148			0.114	2378	774	521	933
149			0.118	2987	881	667	1105
150			0.092	4127	1215	734	1421
151			0.072	7744	1688	1393	2191
AVG	1	IS	0.099	2918	866	673	1051
70	1	SCF(5/4/1/2)	0.106	2328	460	359	584
71			0.103	2953	415	435	601
72			0.100	1719	271	248	368
73			0.120	2938	612	398	730
74			0.115	1422	512	328	609
75			0.115	1297	488	264	555
76			0.113	1016	331	162	369
77			0.113	1313	418	261	494
78			0.102	1734	543	244	596
79			0.122	1141	265	217	343
AVG	1	SCF(5/4/1/2)	0.111	1786	432	303	525

BSC - Bruceton Synthetic Coal; BSS - Bruceton Synthetic Shale; ILL #6 - Illinois #6 Coal; IS - Ilinois Shale-type Material; SCF - Synthetic Coal Formulation (Coal/Ash/Portland Cement).

TABLE A1. LCA CUTTING FORCE RESULTS (Continued)

Cut Number	Depth of Cut (in.)	Material Type	Cut Duration (sec)	Measured Cutting Force (lbf) Peak Value	Mean Value	Standard Deviation	Root-Mean Square
80	1	SCF (5/4/1)	0.109	3359	970	685	1188
81			0.112	3375	729	443	854
82			0.115	3422	1199	705	1391
83			0.111	2422	435	371	572
84			0.120	3000	673	451	811
85			0.103	2438	591	431	731
86			0.116	2250	698	443	827
87			0.112	1672	715	406	823
88			0.117	2719	709	480	857
89			0.122	3496	643	456	788
AVG	1	SCF (5/4/1)	0.114	2813	736	499	884
90	1	SCF(5/4/1-1/2)	0.115	5203	1220	825	1474
91			0.116	5063	1050	700	1263
92			0.119	4242	1018	623	1194
93			0.117	3000	697	522	871
94			0.118	3914	1071	598	1227
95			0.122	3328	788	502	935
96			0.119	3492	1005	597	1170
97			0.120	4336	922	574	1087
98			0.130	3352	654	488	816
99			0.122	3422	864	582	1042
AVG	1	SCF(5/4/1-1/2)	0.120	3935	929	609	1108

BSC - Bruceton Synthetic Coal; BSS - Bruceton Synthetic Shale; ILL #6 - Illinois #6 Coal; IS - Illinois Shale-type Material; SCF - Synthetic Coal Formulation (Coal/Ash/Portland Cement).

Cut Number	Depth of Cut (in.)	Material Type	Cut Duration (sec)	Measured Cutting Force (lbf) Peak Value	Mean Value	Standard Deviation	Root-Mean Square
100	1	SCF (5/4/2)	0.120	4430	1079	751	1315
101			0.121	2789	875	604	1064
102			0.120	2742	1078	564	1218
103			0.130	3539	693	502	856
104			0.126	5086	1568	1027	1875
105			0.124	3586	981	587	1144
106			0.121	5063	1222	876	1504
107			0.117	4547	1229	583	1361
108			0.116	3797	1212	669	1386
109			0.122	5156	1304	834	1549
AVG	1	SCF (5/4/2)	0.122	4073	1124	717	1327
110	1	SCF(5/2-1/2/2)	0.120	3305	862	461	978
111			0.122	3422	917	661	1131
112			0.121	3469	966	549	1121
113			0.136	3445	946	652	1150
114			0.110	5039	1348	769	1553
115			0.115	4945	1166	714	1369
116			0.139	5063	1248	914	1548
117			0.125	4758	1256	804	1492
118			0.124	5109	1475	845	1701
119			0.124	5109	1640	985	1914
AVG	1	SCF(5/2-1/2/2)	0.124	4366	1183	751	1395

BSC - Bruceton Synthetic Coal; BSS - Bruceton Synthetic Shale; ILL #6 - Illinois #6 Coal; IS - Illinois Shale-type Material; SCF - Synthetic Coal Formulation (Coal/Ash/Portland Cement).

TABLE A1. LCA CUTTING FORCE RESULTS (Concluded)

Cut Number	Depth of Cut (in.)	Material Type	Cut Duration (sec)	Measured Cutting Force (lbf)			
				Peak Value	Mean Value	Standard Deviation	Root-Mean Square
120	1	SCF(5/3-1/2/1)	0.116	4734	895	668	1118
121			0.124	3656	1081	640	1257
122			0.118	4875	1186	719	1388
123			0.119	4547	883	631	1086
124			0.119	2602	786	427	895
125			0.129	2227	811	494	950
126			0.118	3188	723	484	870
127			0.119	2320	624	432	759
128			0.118	3516	830	587	1017
129			0.119	2203	890	452	999
AVG	1	SCF(5/3-1/2/1)	0.120	3387	871	563	1034
130	1	SCF(5/3/1-1/2)	0.122	3211	1232	619	1380
131			0.128	3328	919	600	1098
132			0.124	5508	1105	719	1319
133			0.145	5086	900	768	1183
134			0.121	5555	1360	858	1609
135			0.114	5180	965	741	1217
136			0.123	4992	1196	694	1384
137			0.121	4758	980	674	1190
138			0.118	4758	1216	690	1399
139			0.125	3914	1167	672	1347
AVG	1	SCF(5/3/1-1/2)	0.124	4629	1104	707	1313

BSC - Bruceton Synthetic Coal; BSS - Bruceton Synthetic Shale; ILL #6 - Illinois #6 Coal; IS - Illinois Shale-type Material; SCF - Synthetic Coal Formulation (Coal/Ash/Portland Cement).

TABLE A2. LCA SENSITIZED PICK RESULTS

Cut Number	Depth of Cut (in.)	Material Type	Cut Duration (sec)	Measured Cutting Parameters (volts) Peak Value	Mean Value	Standard Deviation	Root-Mean Square
152	1	ILL #6	0.109	-39.1	-2.8	5.3	-6.0
153	↓	↓	0.088	-32.0	-3.8	4.0	-5.5
154			0.094	-41.4	-4.8	6.4	-7.9
155			0.088	-45.3	-7.4	6.8	-10.0
156			0.094	-38.7	-4.3	5.2	-6.8
157			0.094	-29.7	-4.3	4.7	-6.4
158			0.078	-38.3	-7.9	7.0	-10.6
159			0.051	-33.6	-2.7	4.5	-5.2
160			0.095	-37.1	-4.4	4.9	-6.5
AVG			0.088	-37.2	-4.7	5.5	-7.2
161	1	IS	0.098	-14.5	-1.1	1.1	-1.6
162	↓	↓	0.109	-22.3	-0.9	1.8	-2.0
163			0.085	-16.8	-1.3	1.7	-2.1
164			0.093	-12.3	-1.2	1.5	-1.9
165			0.100	-22.3	-1.1	2.0	-2.2
166			0.118	-44.9	-3.3	4.8	-5.7
167			0.112	-15.6	-0.9	1.4	-1.7
168			0.121	-35.9	-2.2	3.7	-4.3
AVG			0.105	-23.1	-1.5	2.6	-2.7

ILL #6 - Illinois #6 Coal; IS - Illinois Shale-type Material.

APPENDIX B

LCA TIME HISTORIES

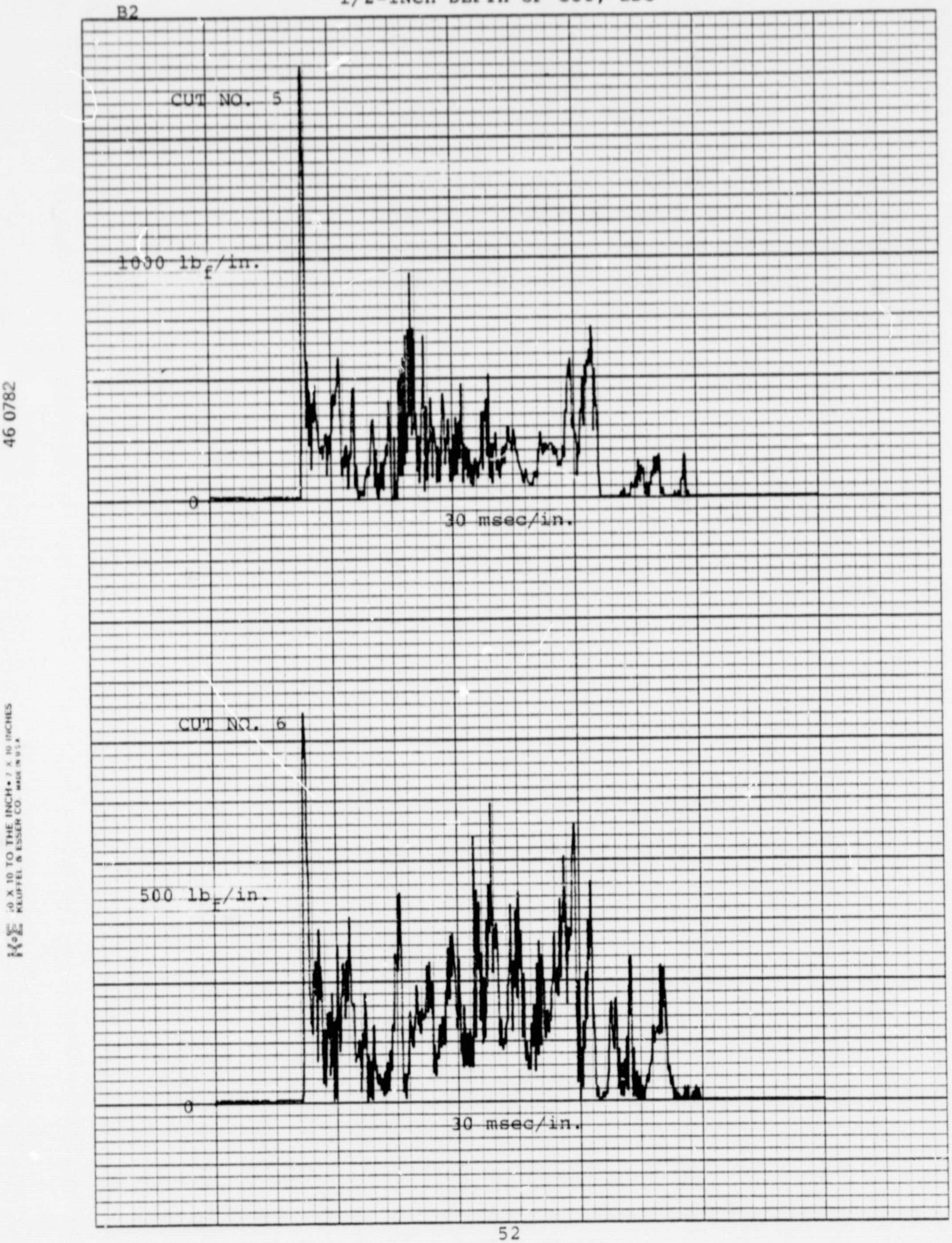
APPENDIX B

LCA TIME HISTORIES

This appendix contains the time histories from which the results given in appendix A were derived. Time histories associated with synthetic coal and shale formula evaluation have not been included. The time histories are presented by individual cut number.

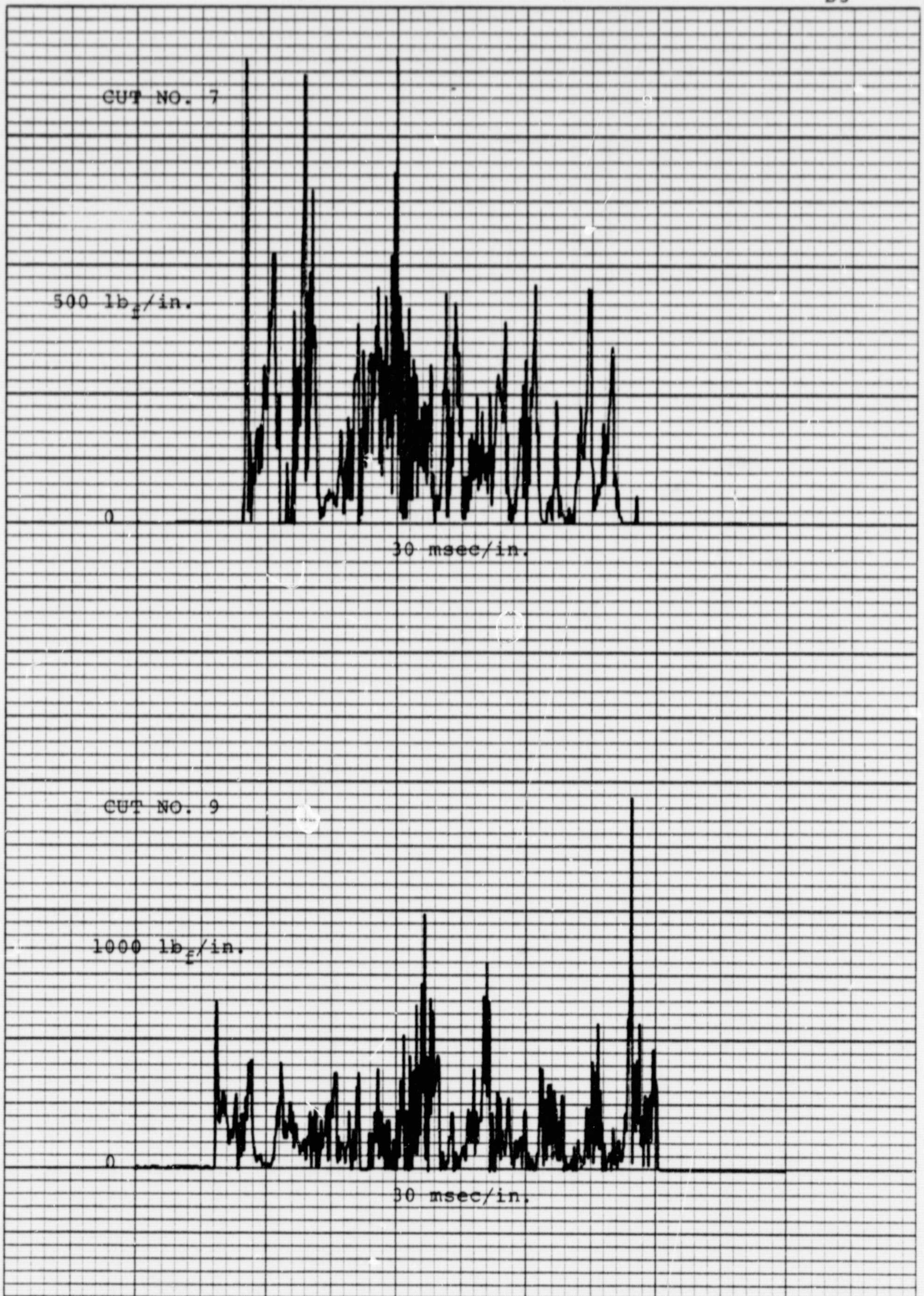
ORIGINAL PAGE IS
OF POOR QUALITY

1/2-INCH DEPTH OF CUT, BSC



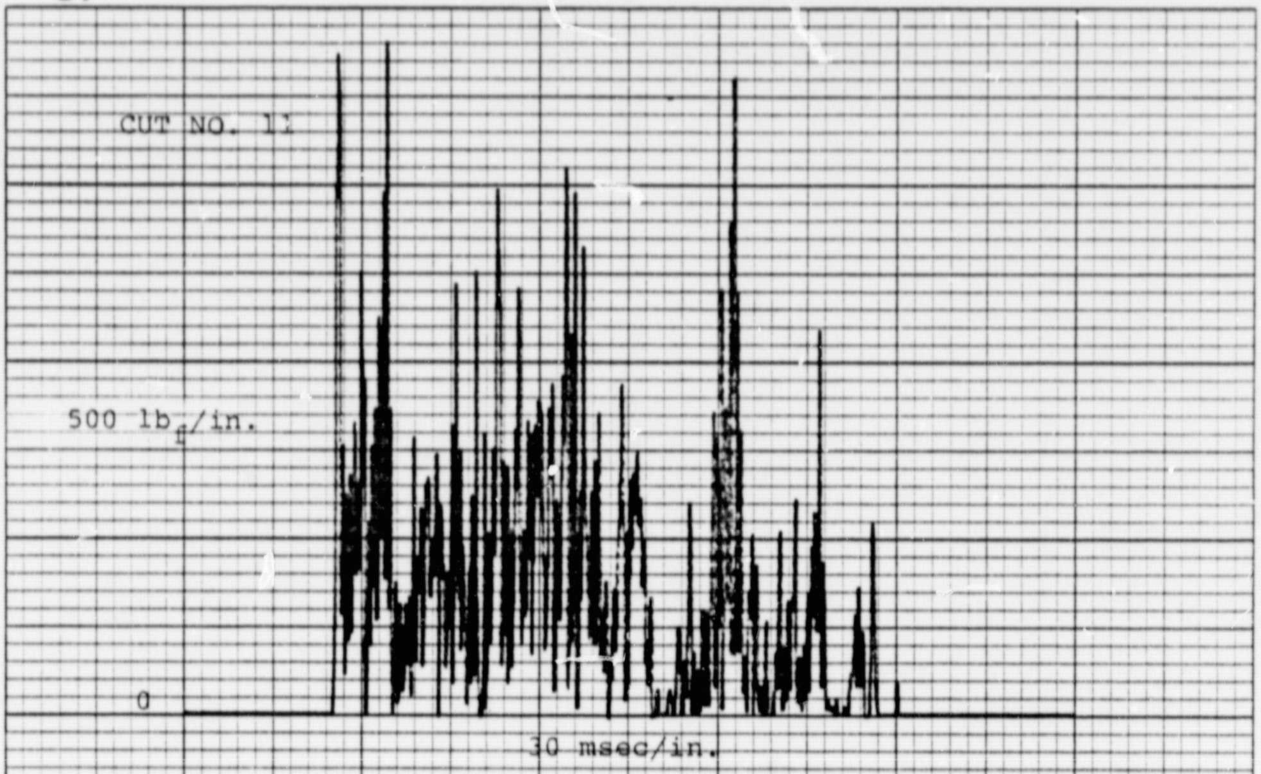
ORIGINAL PAGE IS
OF POOR QUALITY

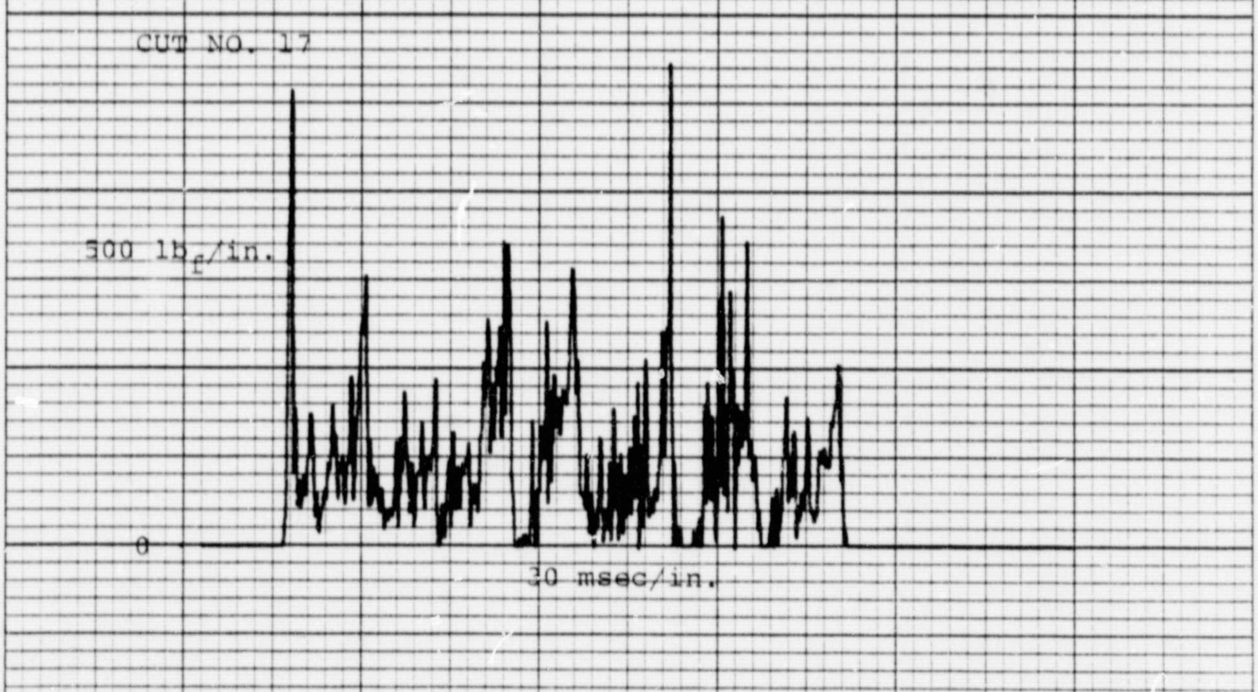
1/2-INCH DEPTH OF CUT, BSC



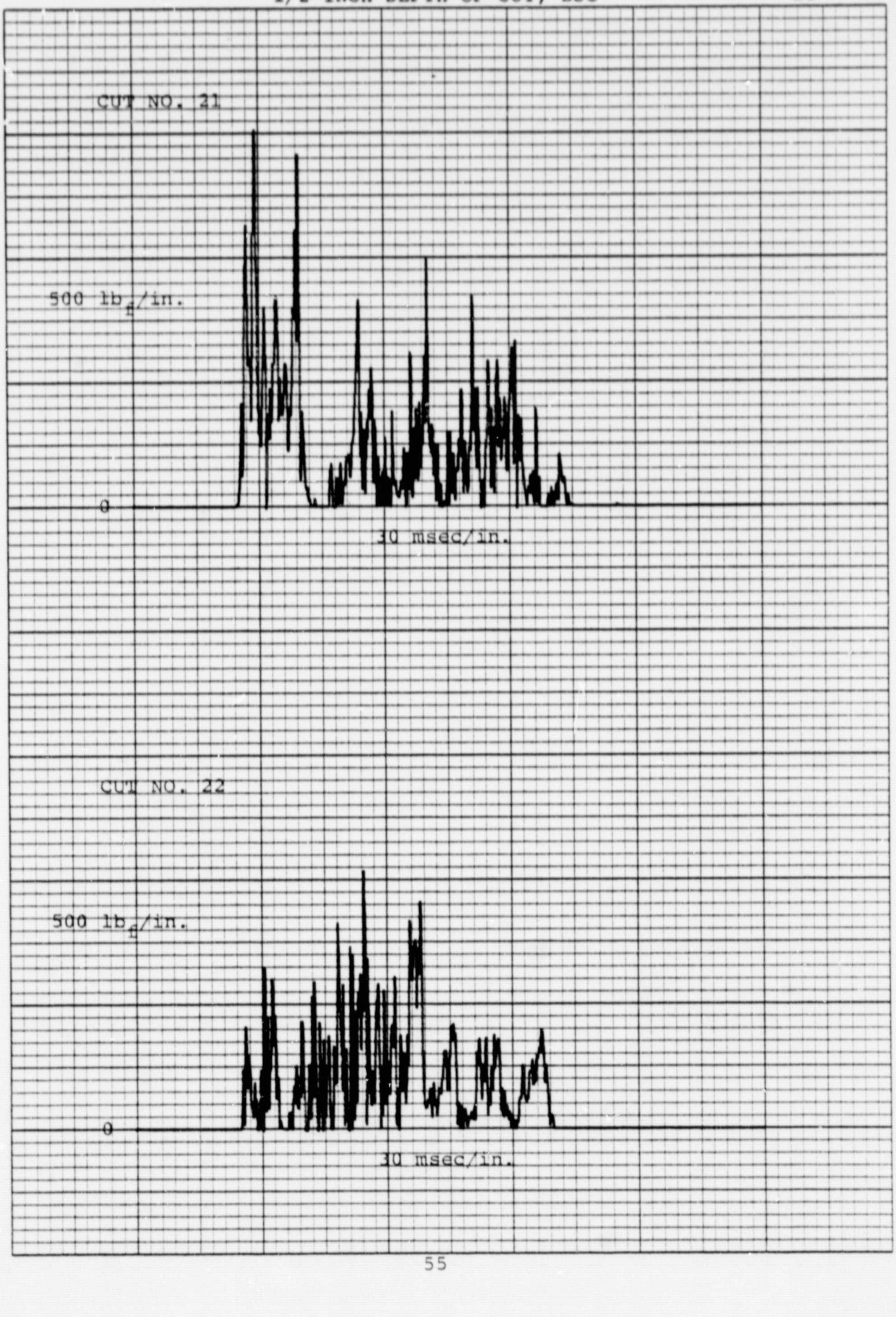
1/2-INCH DEPTH OF CUT, BSC

B4



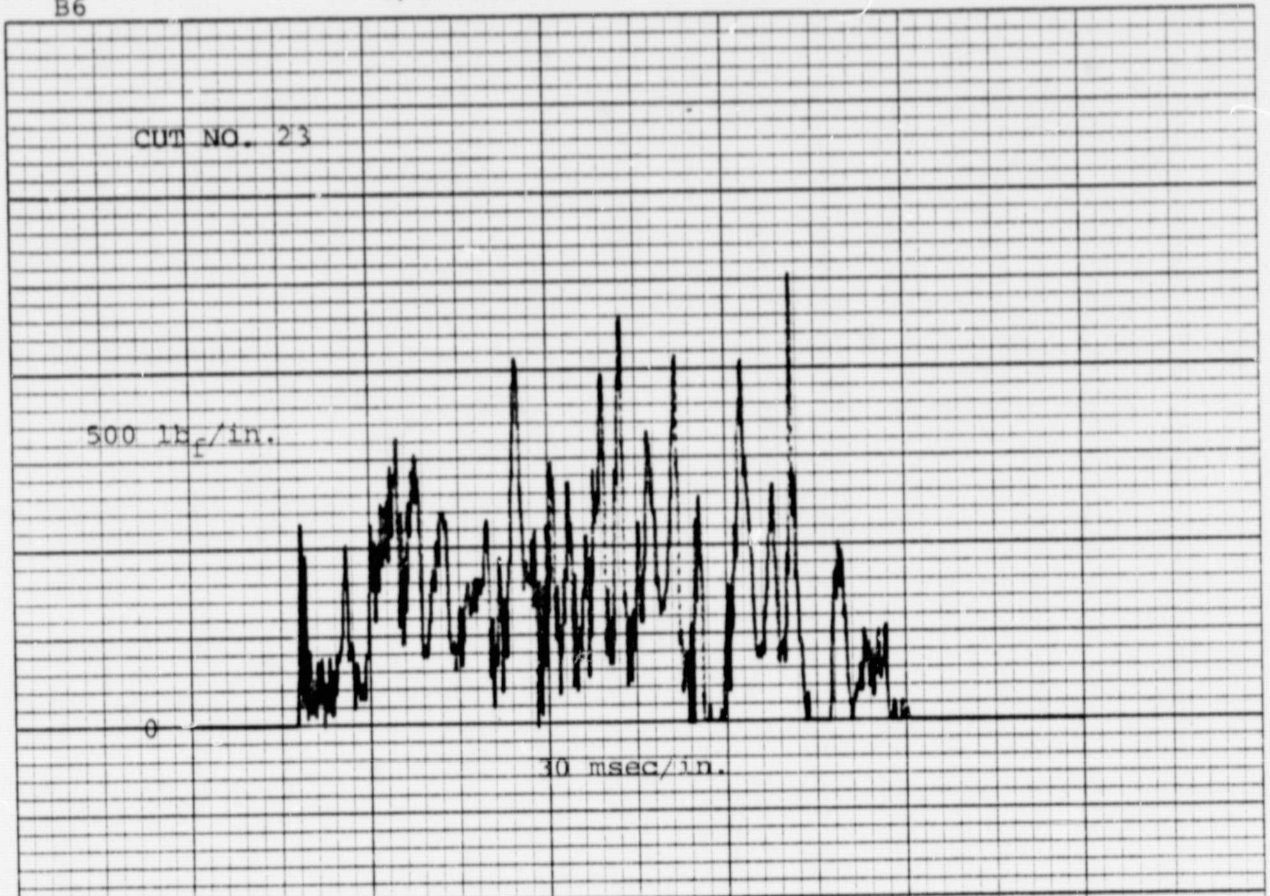


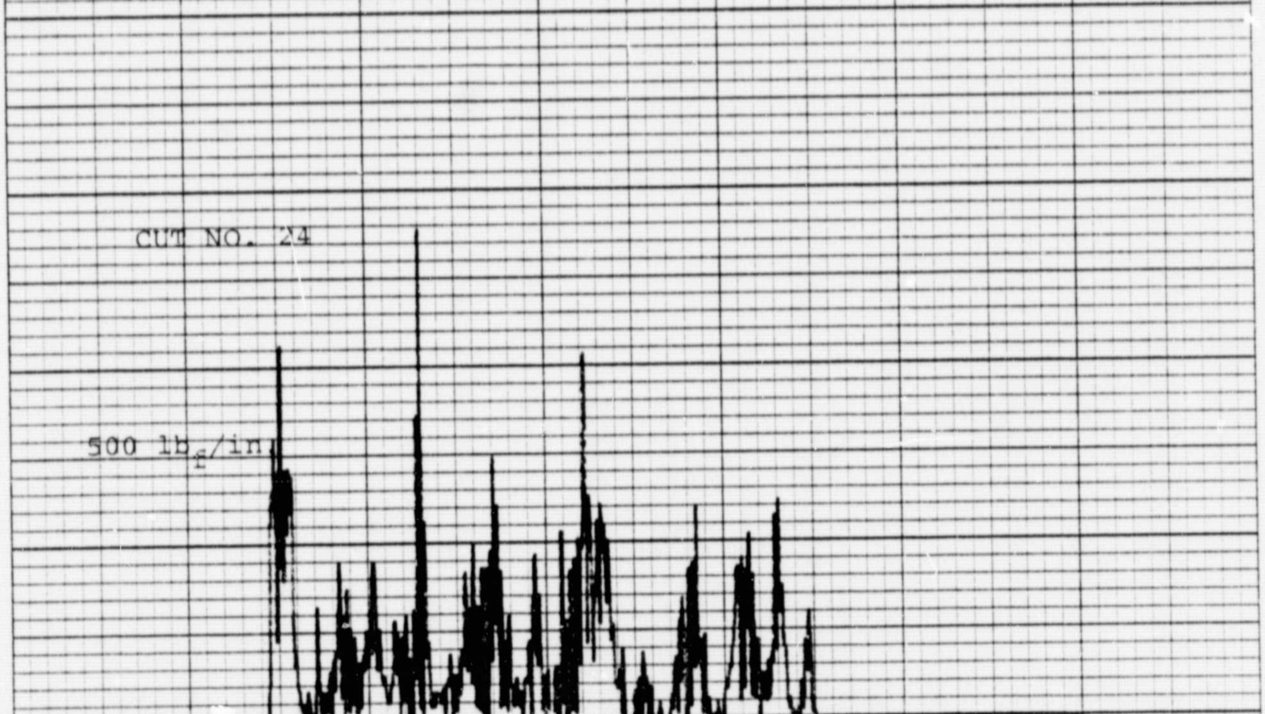
1/2-INCH DEPTH OF CUT, BSC



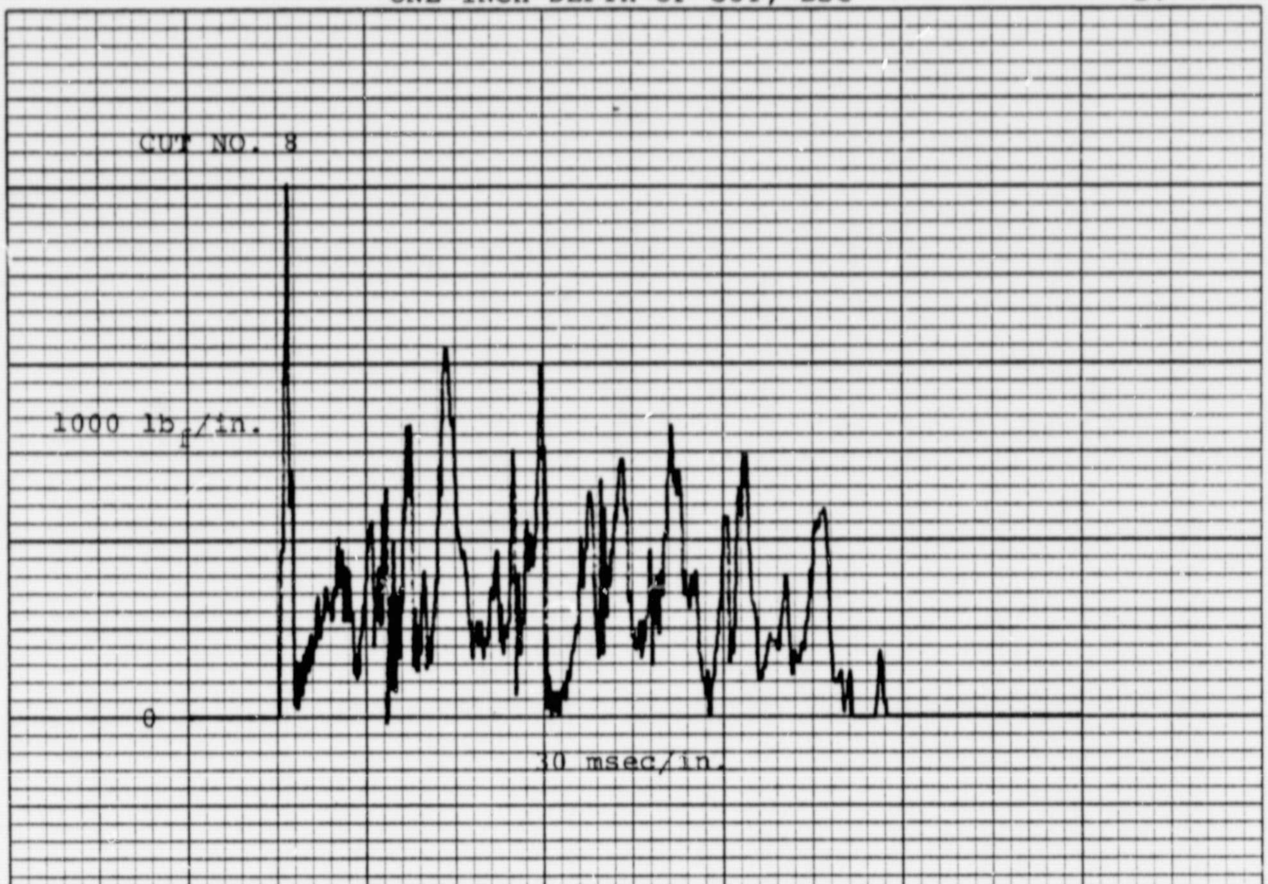
1/2-INCH DEPTH OF CUT, BSC

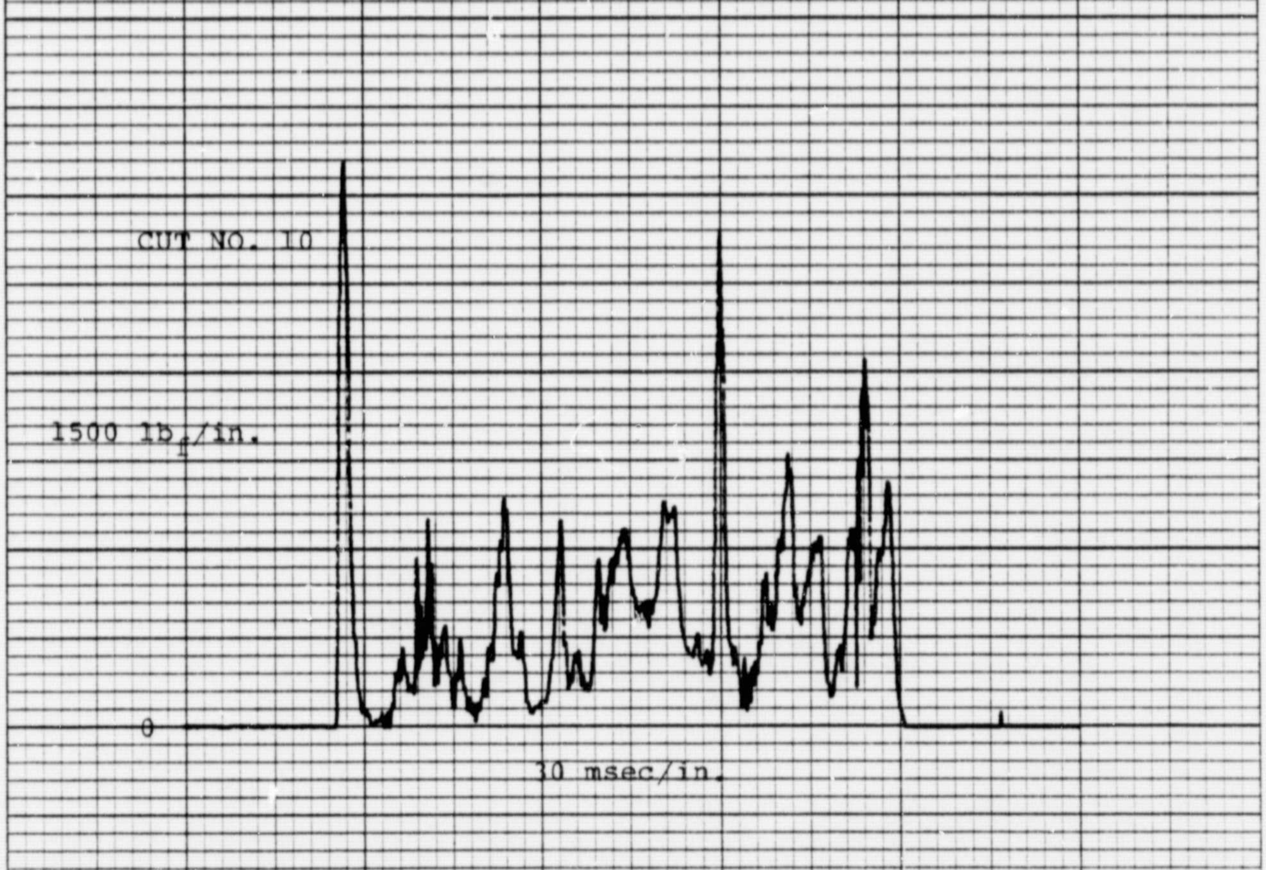
B6





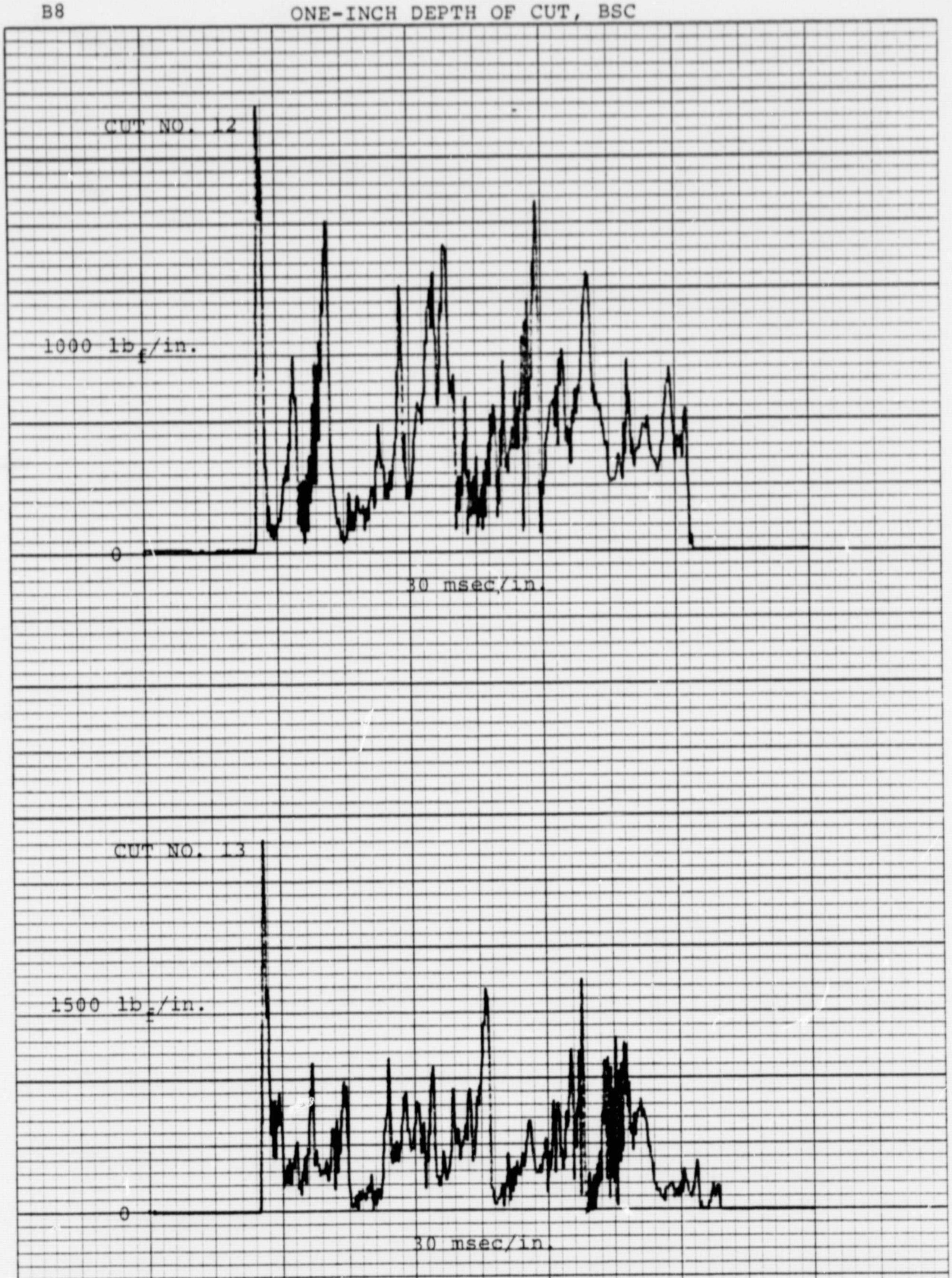
ONE-INCH DEPTH OF CUT, BSC

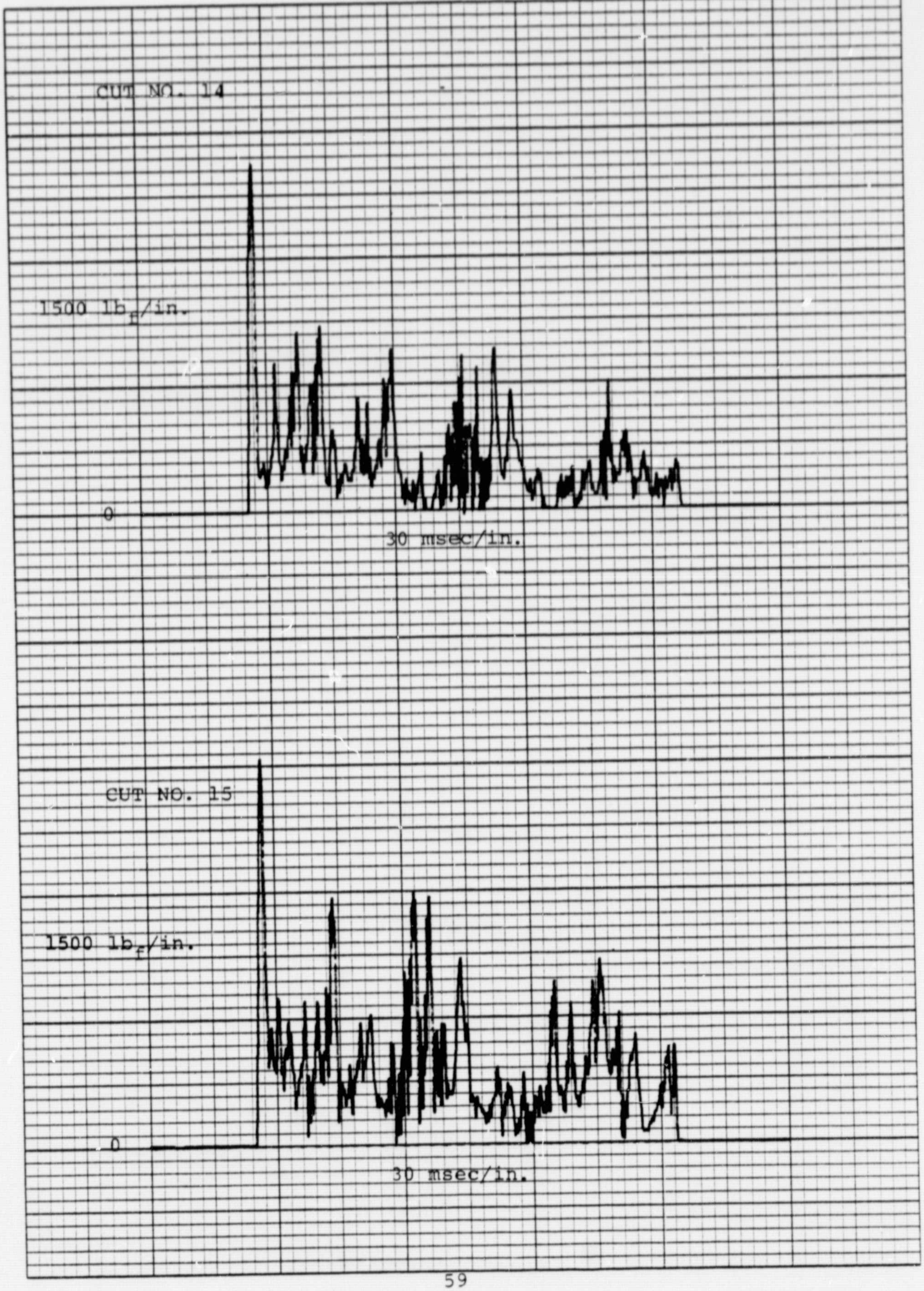




B8

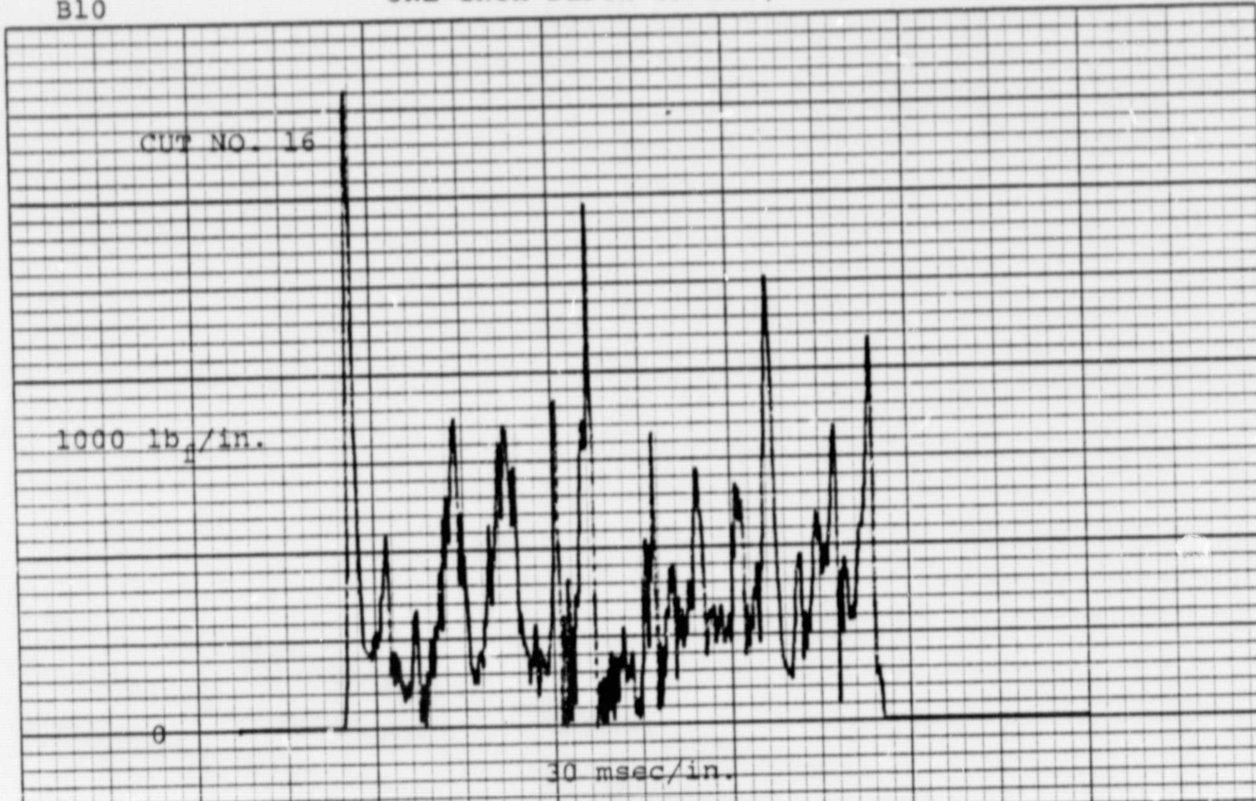
ONE-INCH DEPTH OF CUT, BSC

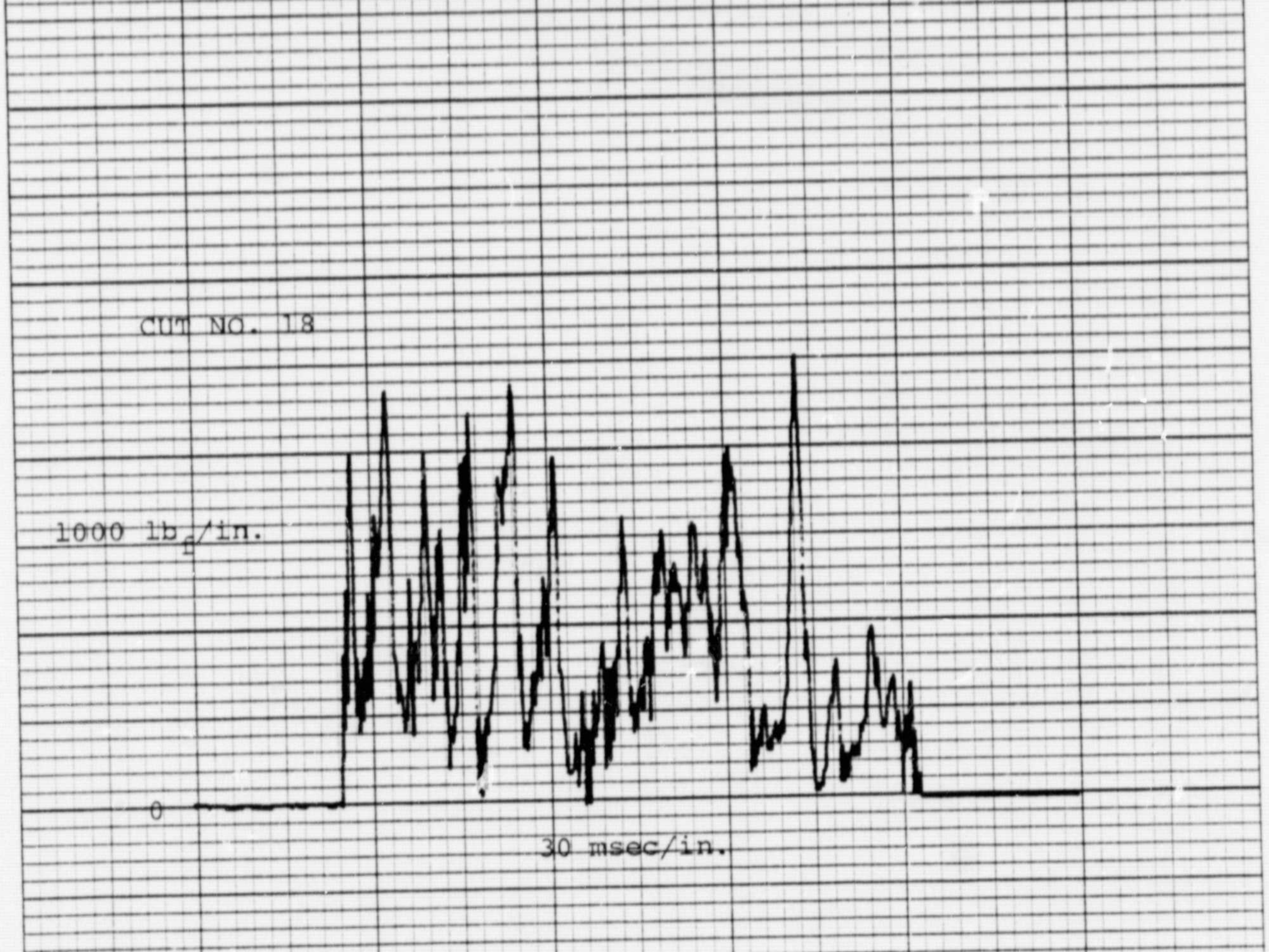



CUT NO. 14
1500 lb_f/in.
0
30 msec/in.
CUT NO. 15
1500 lb_f/in.
0
30 msec/in.

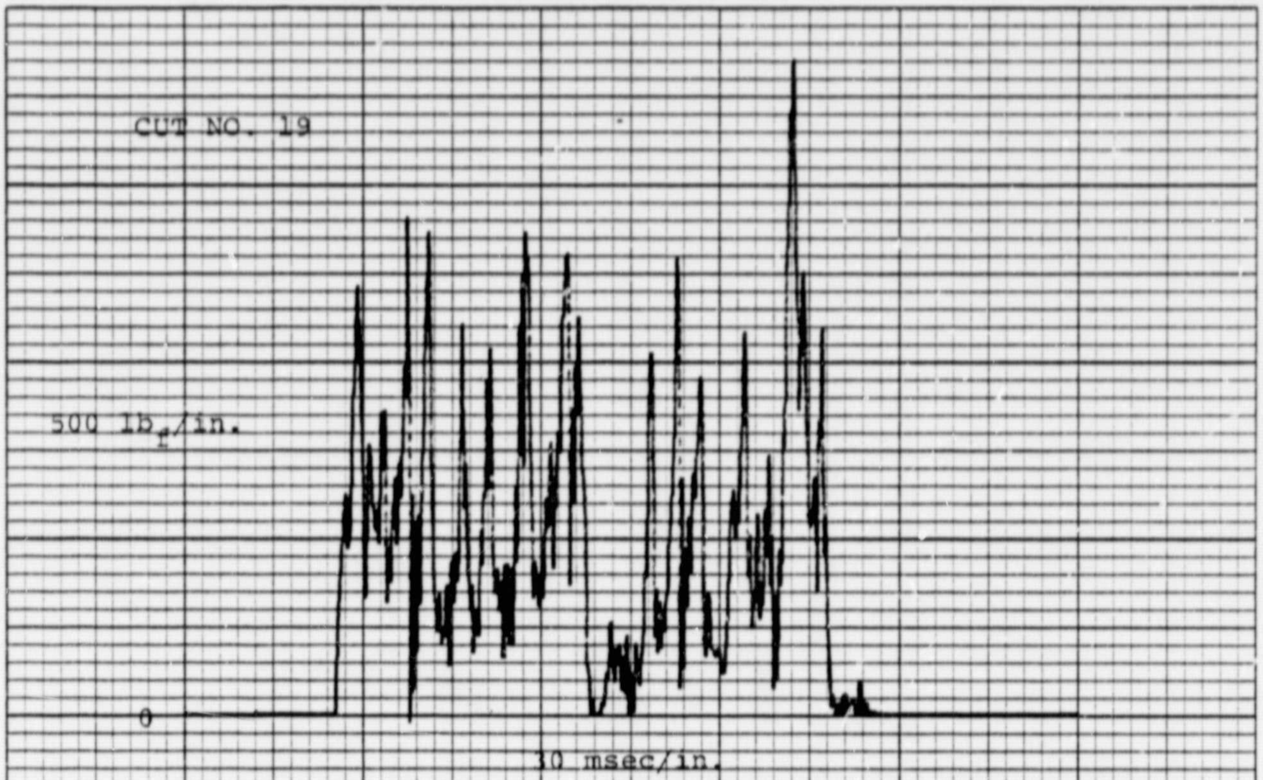
B10

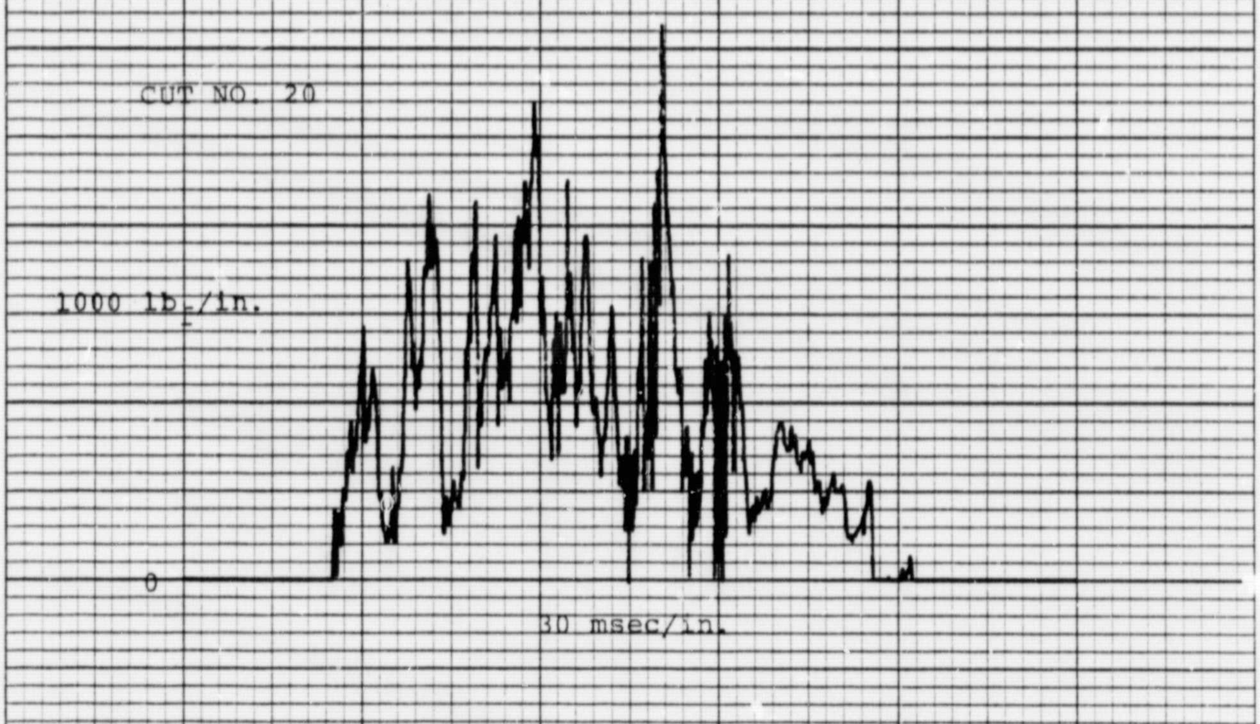
ONE-INCH DEPTH OF CUT, BSC



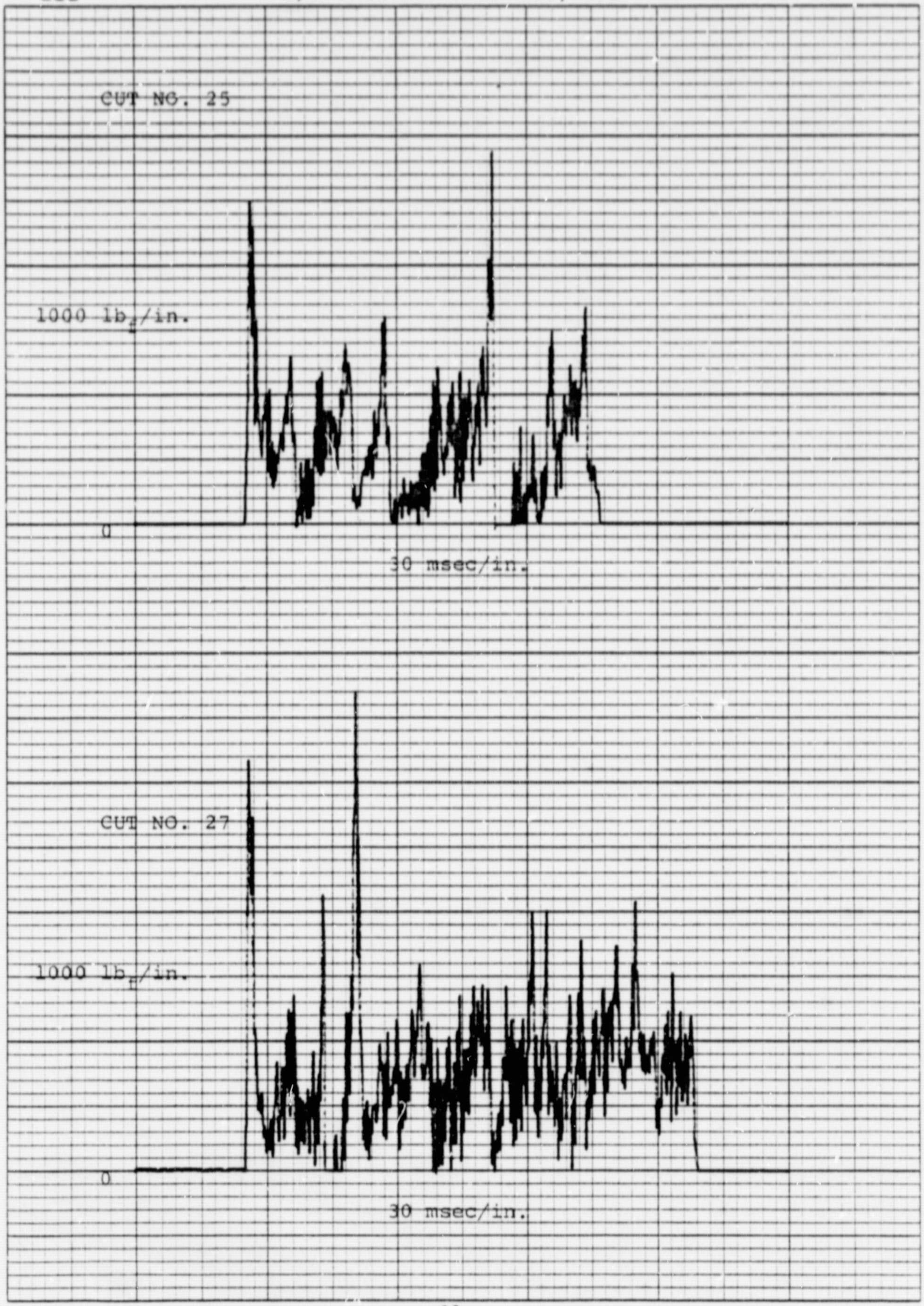


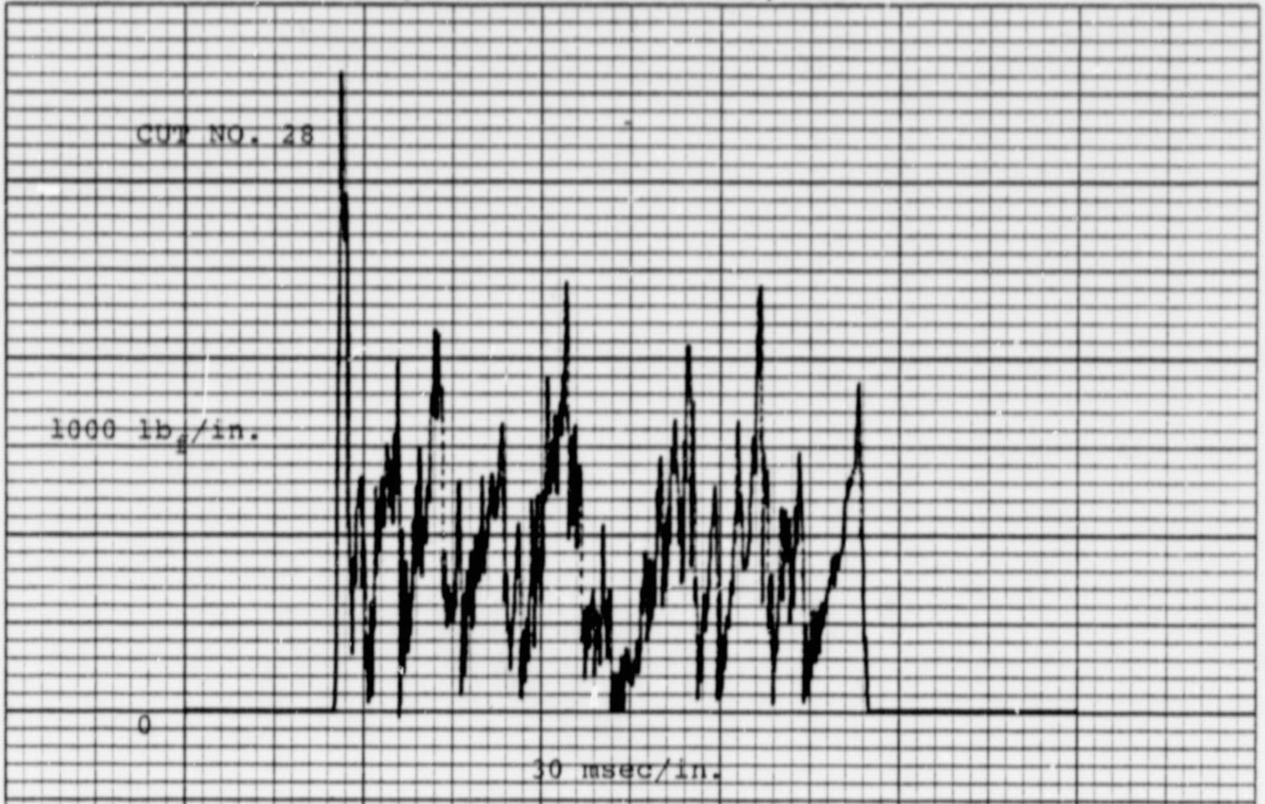
ONE-INCH DEPTH OF CUT, BSC

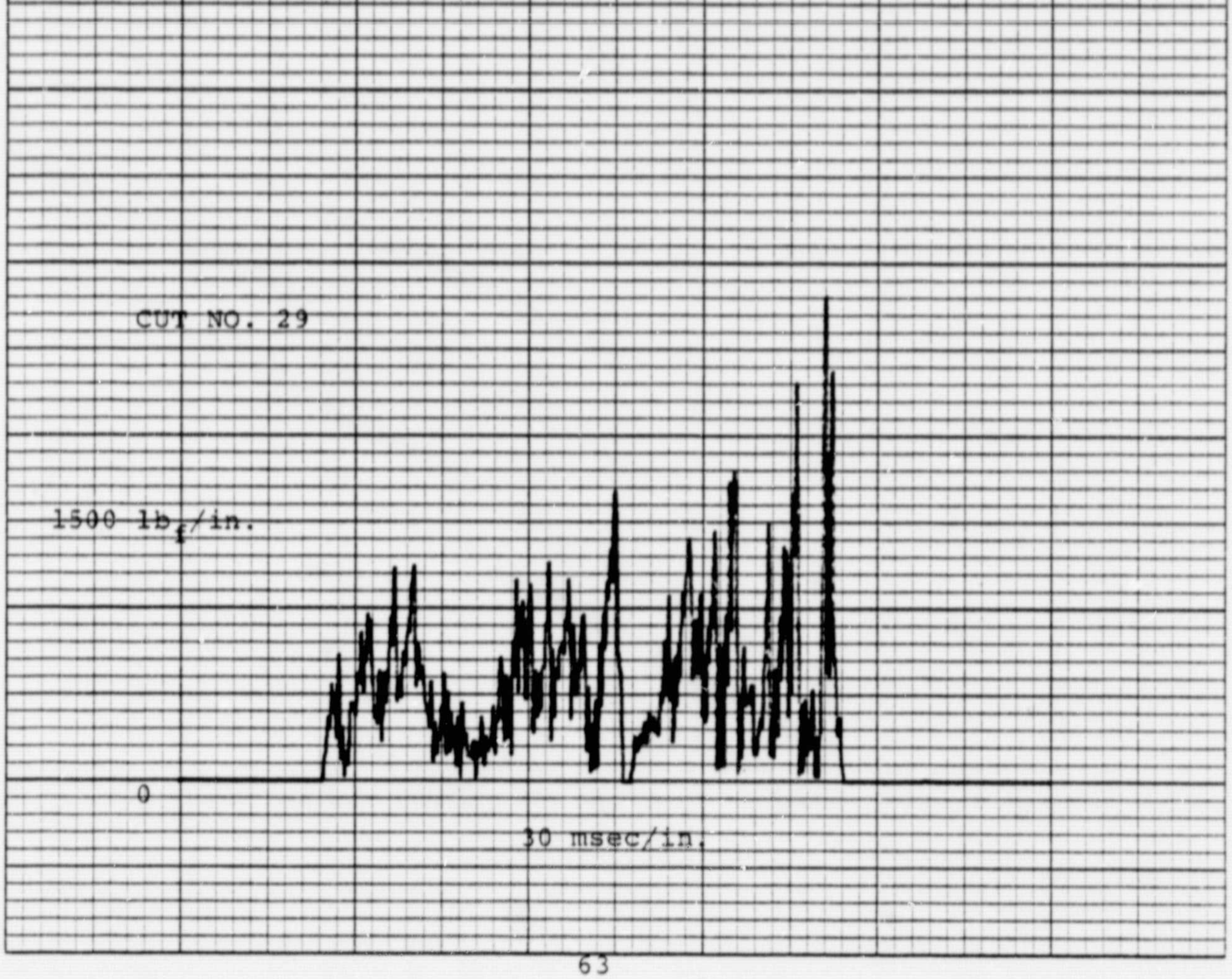




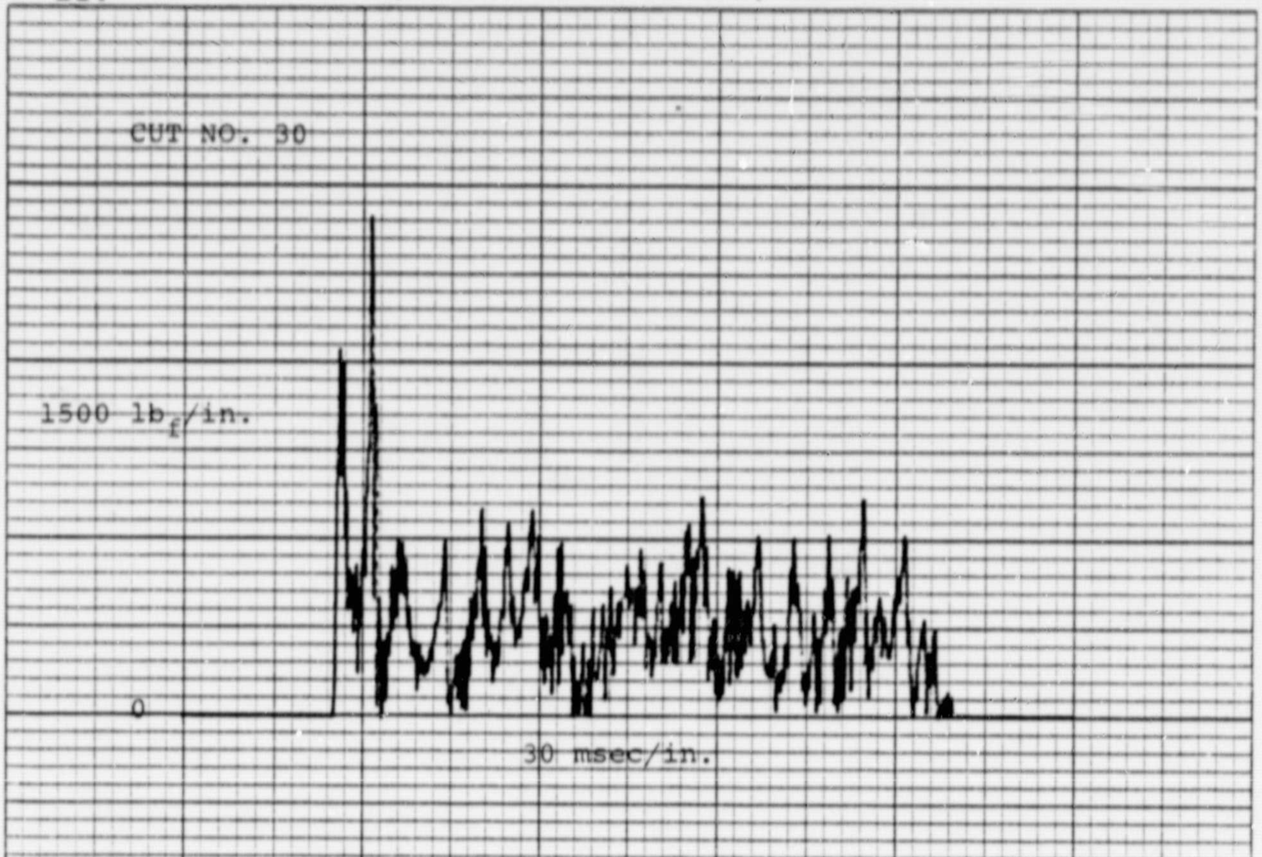
B12 1/2-INCH DEPTH OF CUT, BSS

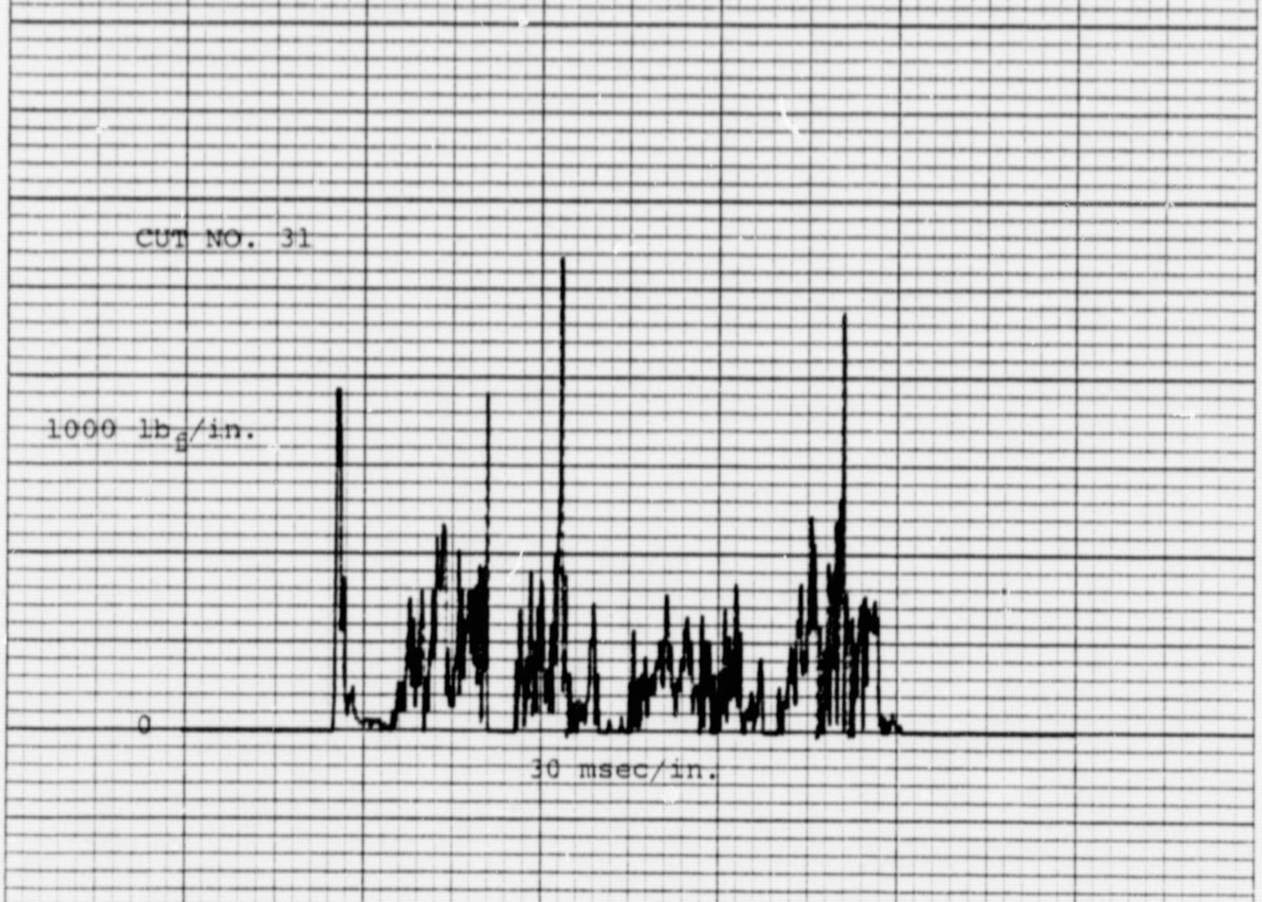



CUT NO. 28
1000 lb$_f$/in.
0
30 msec/in.

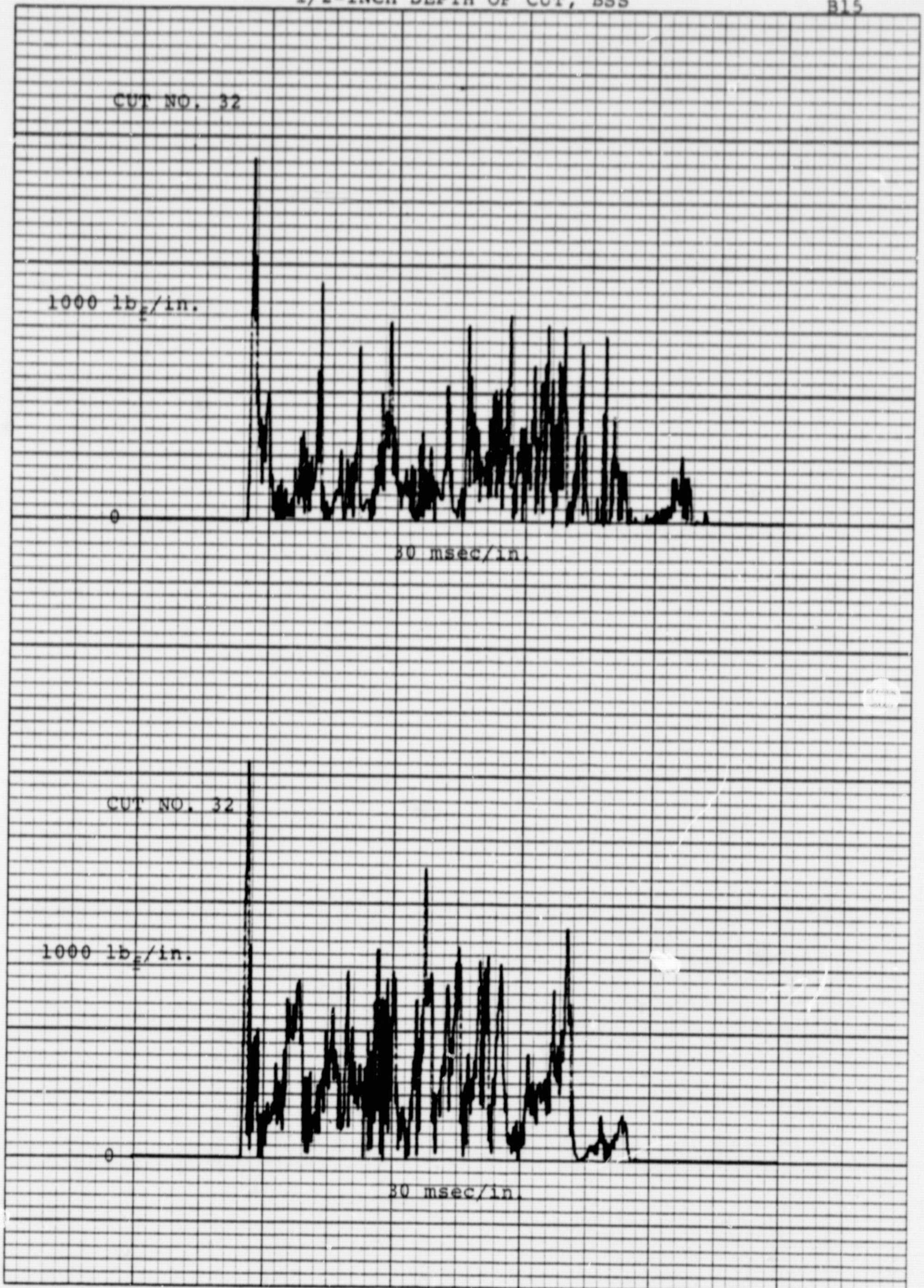

CUT NO. 29
1500 lb$_f$/in.
0
30 msec/in.

B14 1/2-INCH DEPTH OF CUT, BSS



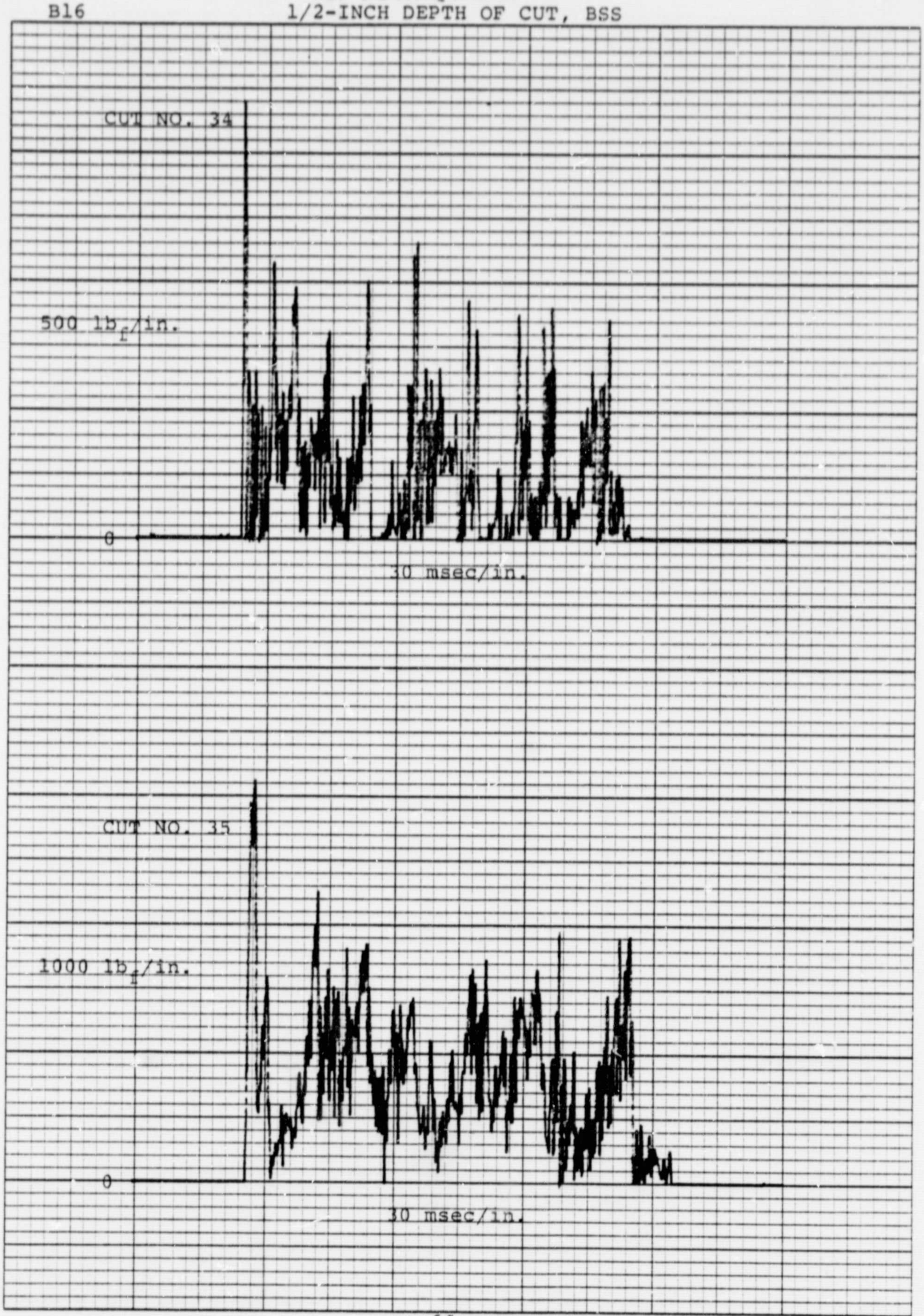


1/2-INCH DEPTH OF CUT, BSS



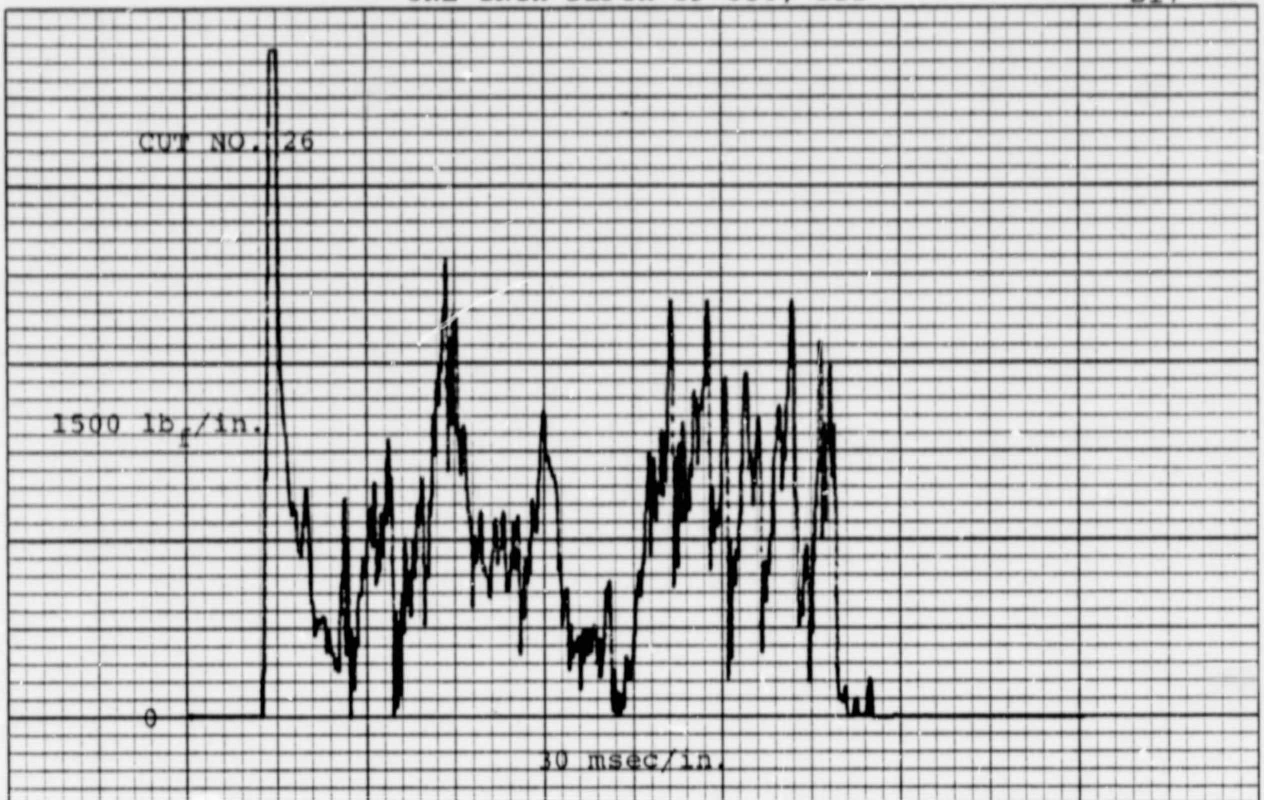
B16

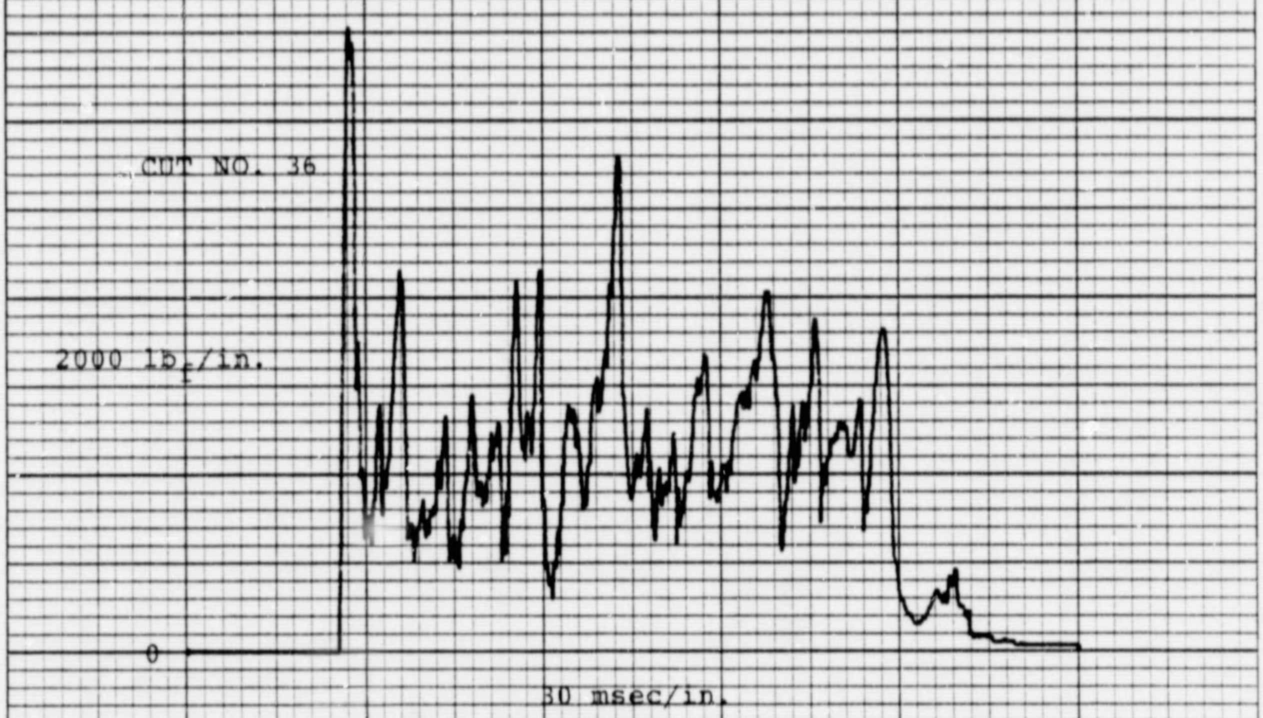
1/2-INCH DEPTH OF CUT, BSS



ORIGINAL PAGE IS
OF POOR QUALITY

ONE-INCH DEPTH OF CUT, BSS

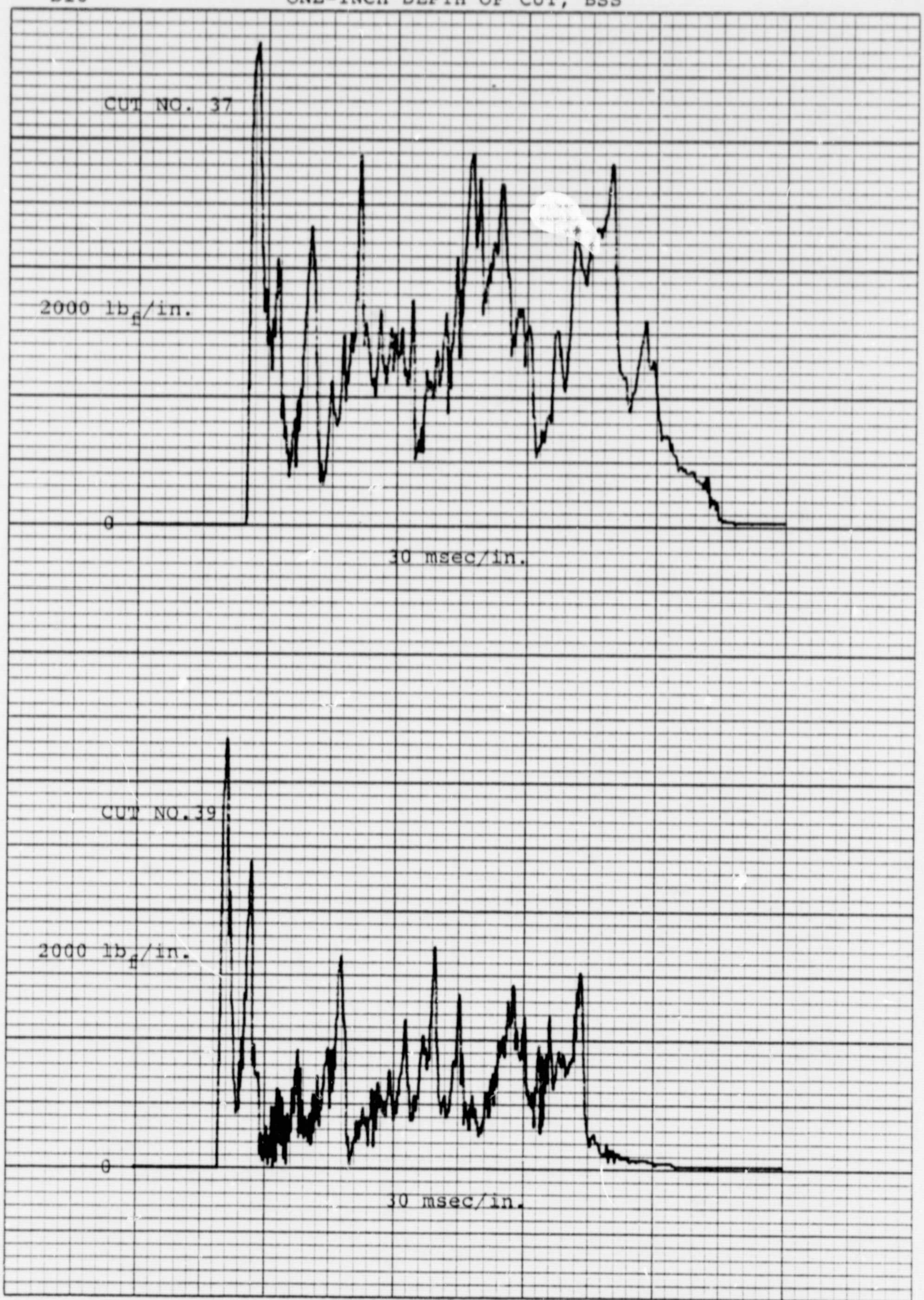




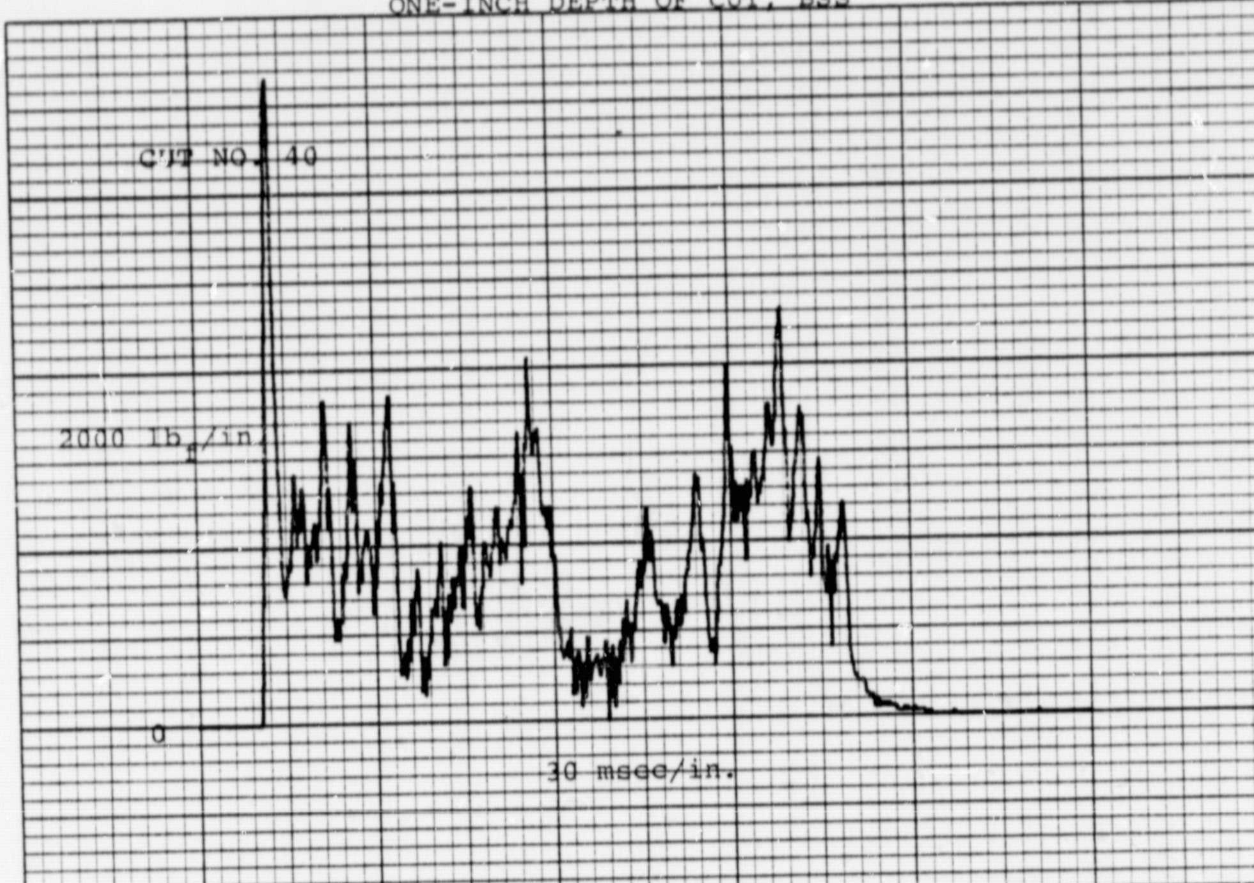
46 0782

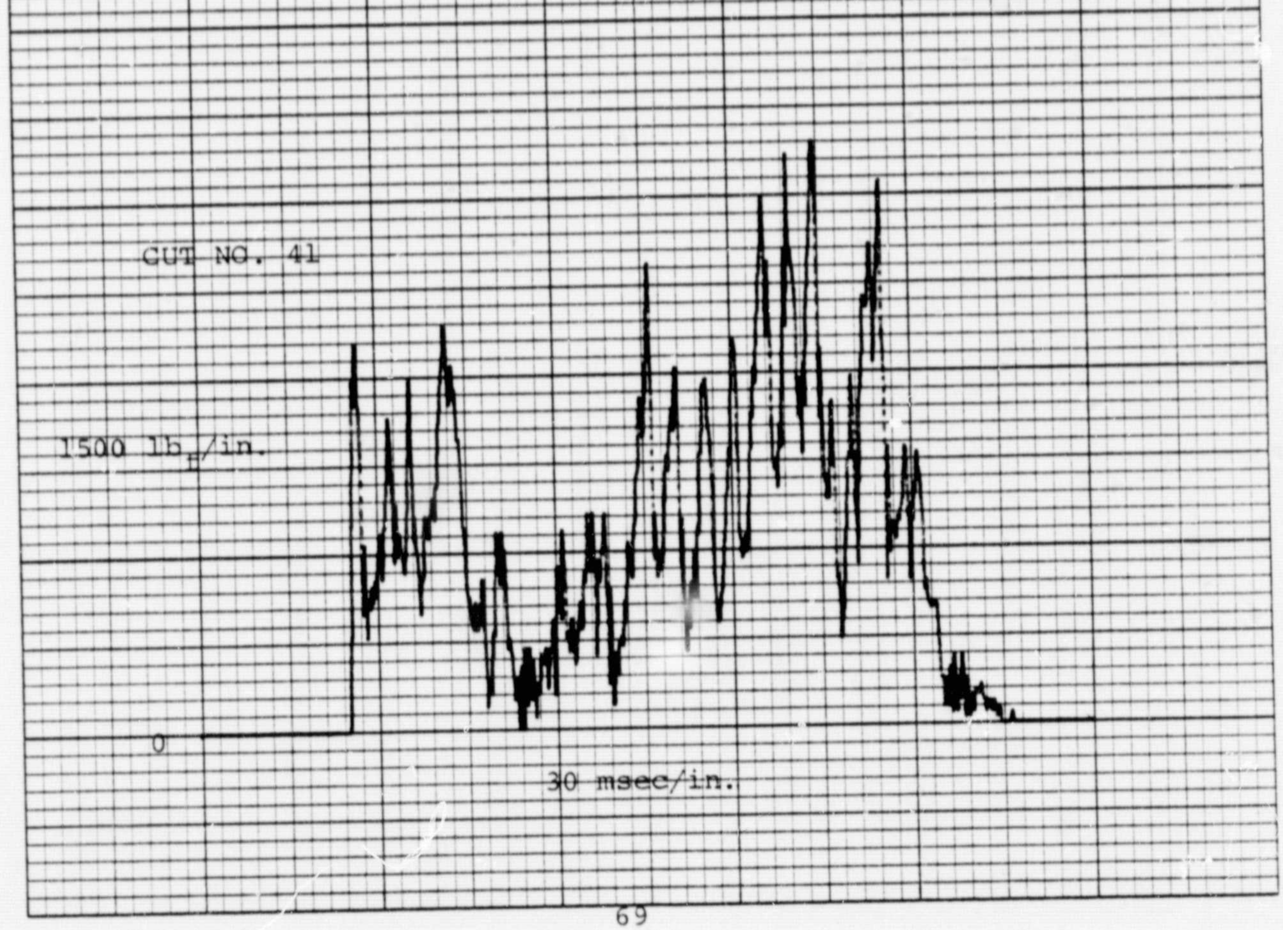
K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

ONE-INCH DEPTH OF CUT, BSS

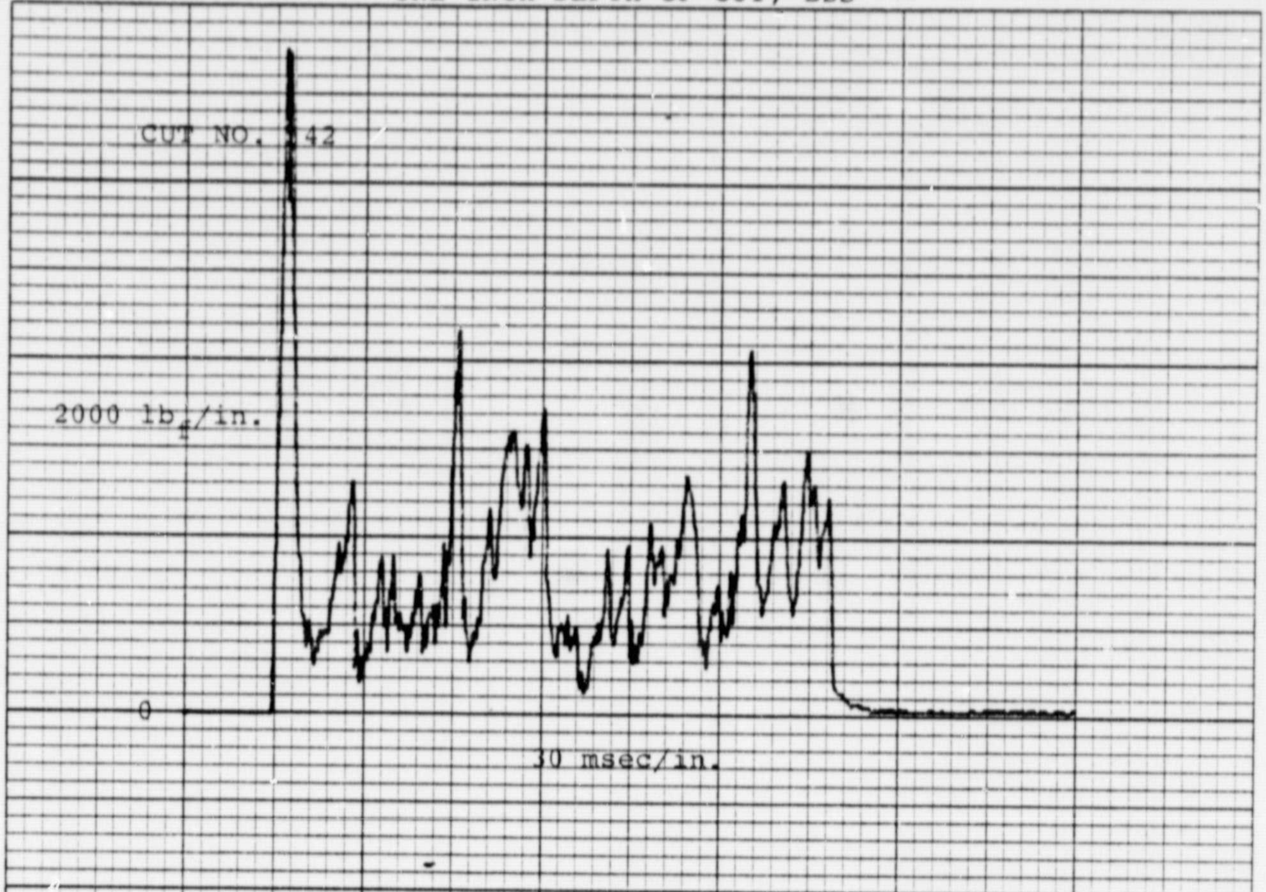


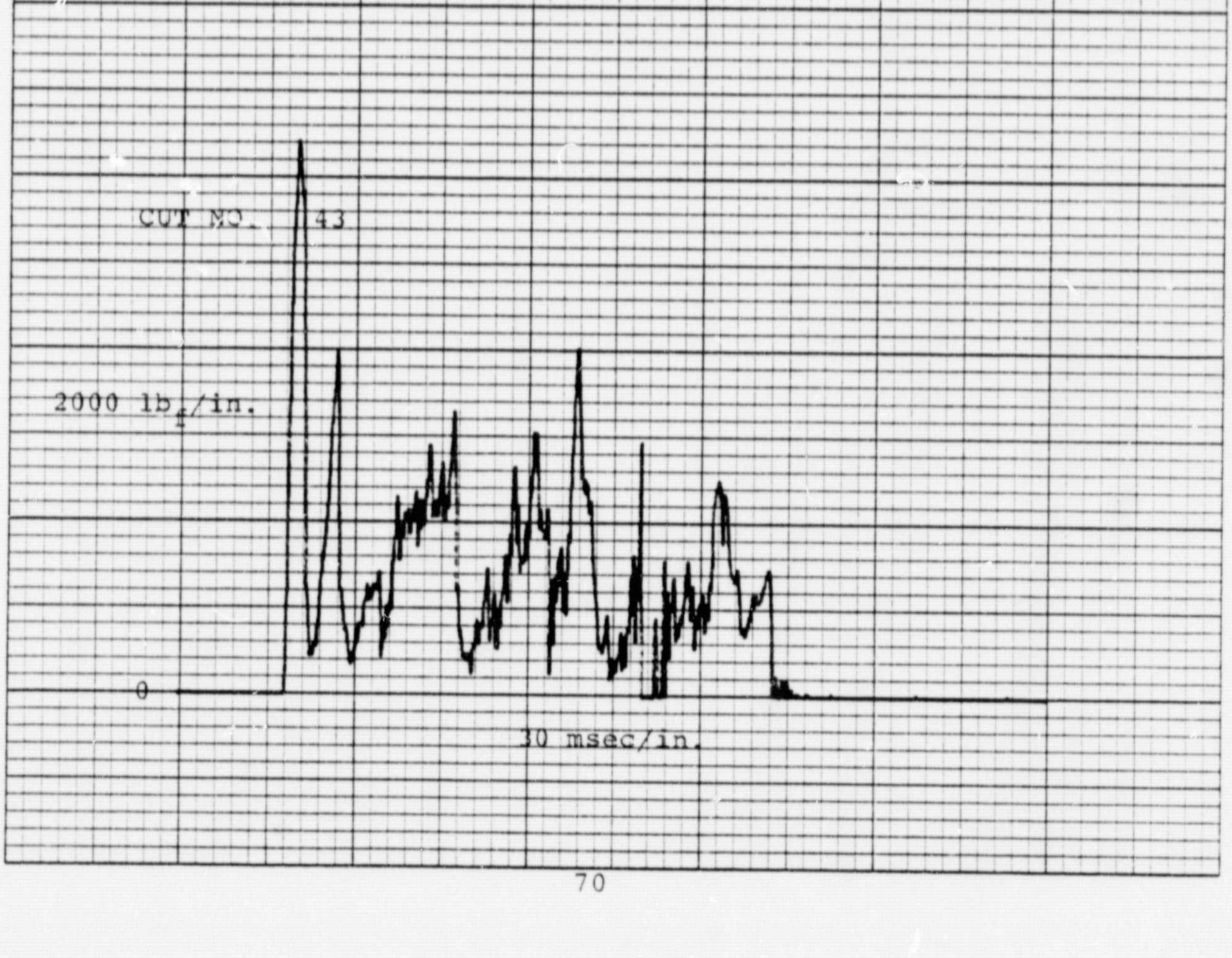
ONE-INCH DEPTH OF CUT, BSS



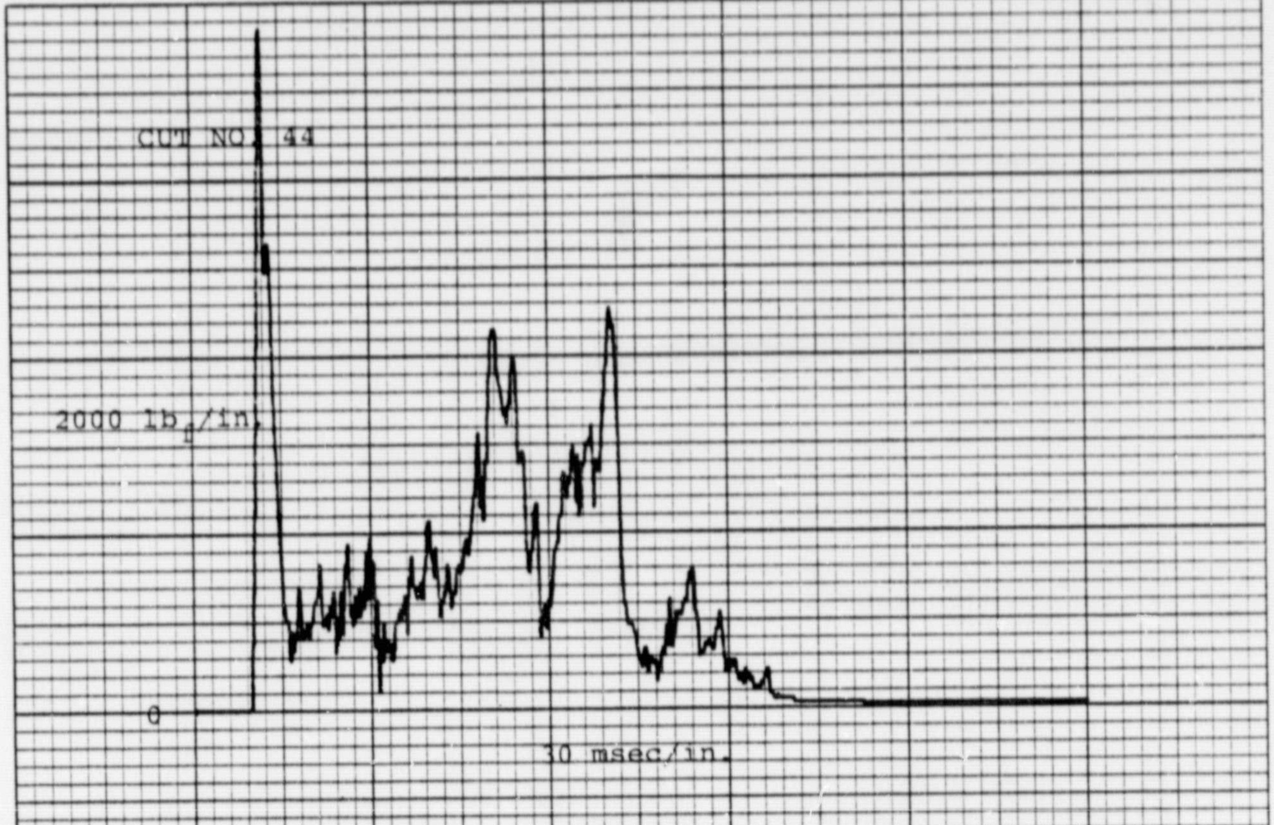


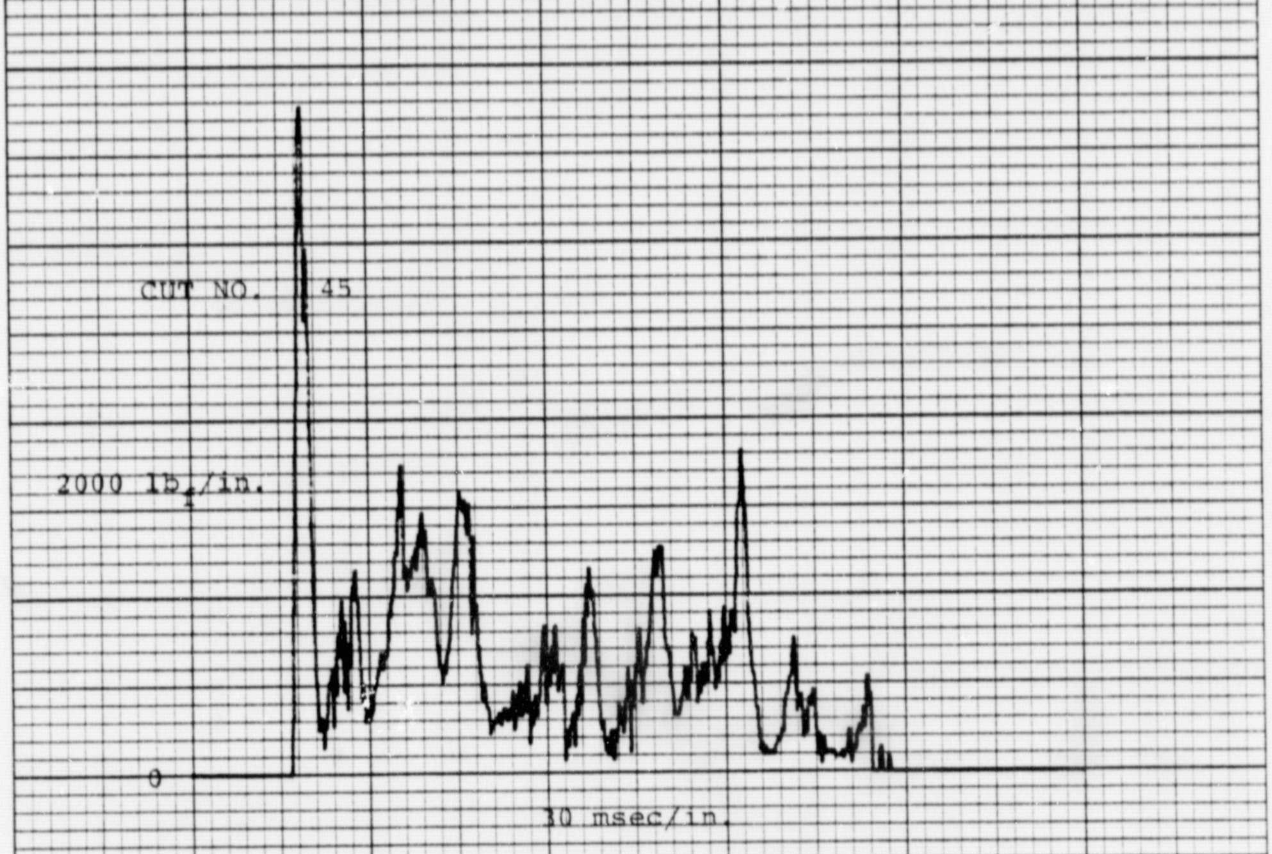
ONE-INCH DEPTH OF CUT, BSS





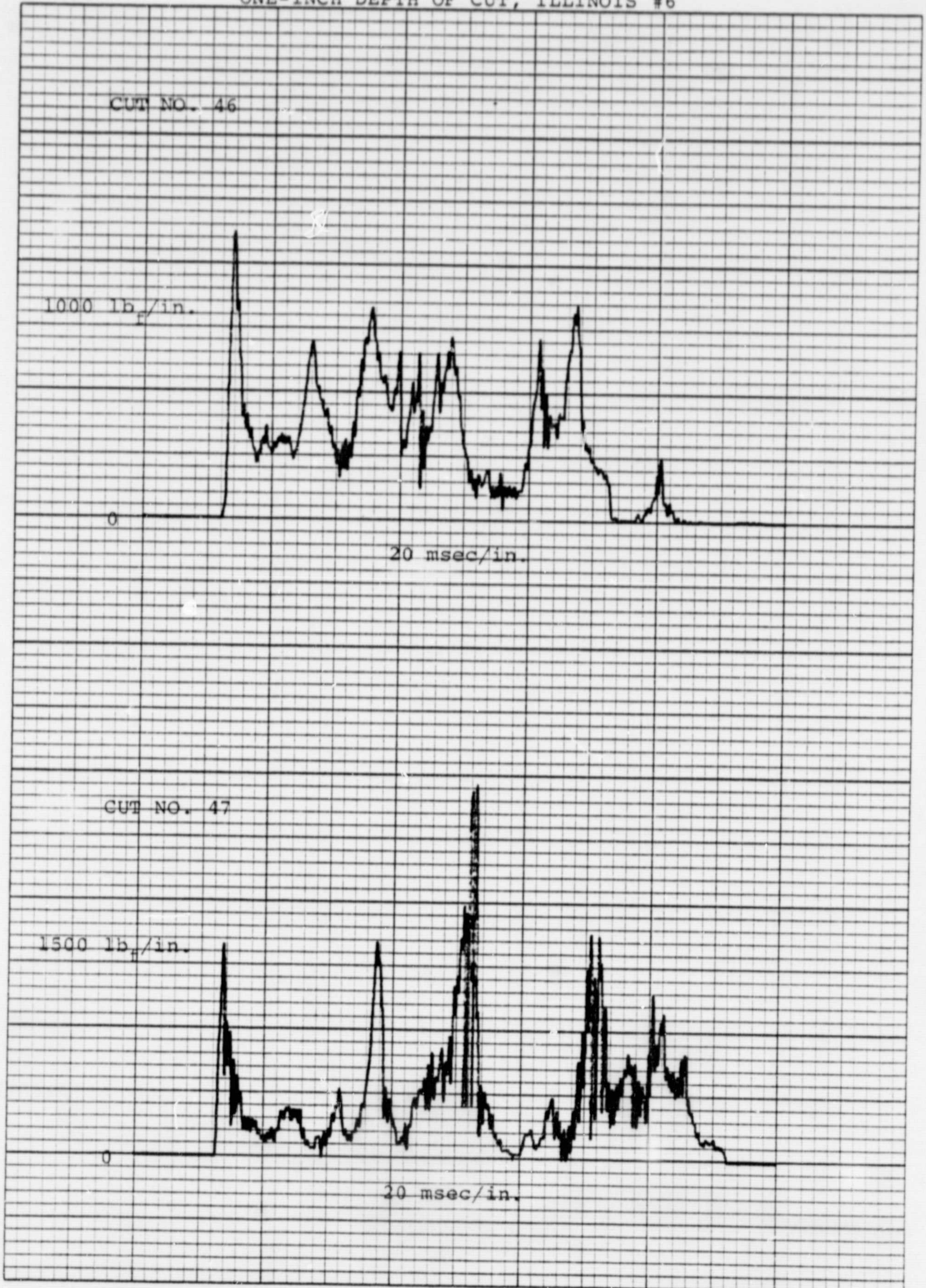
ONE-INCH DEPTH OF CUT, BSS



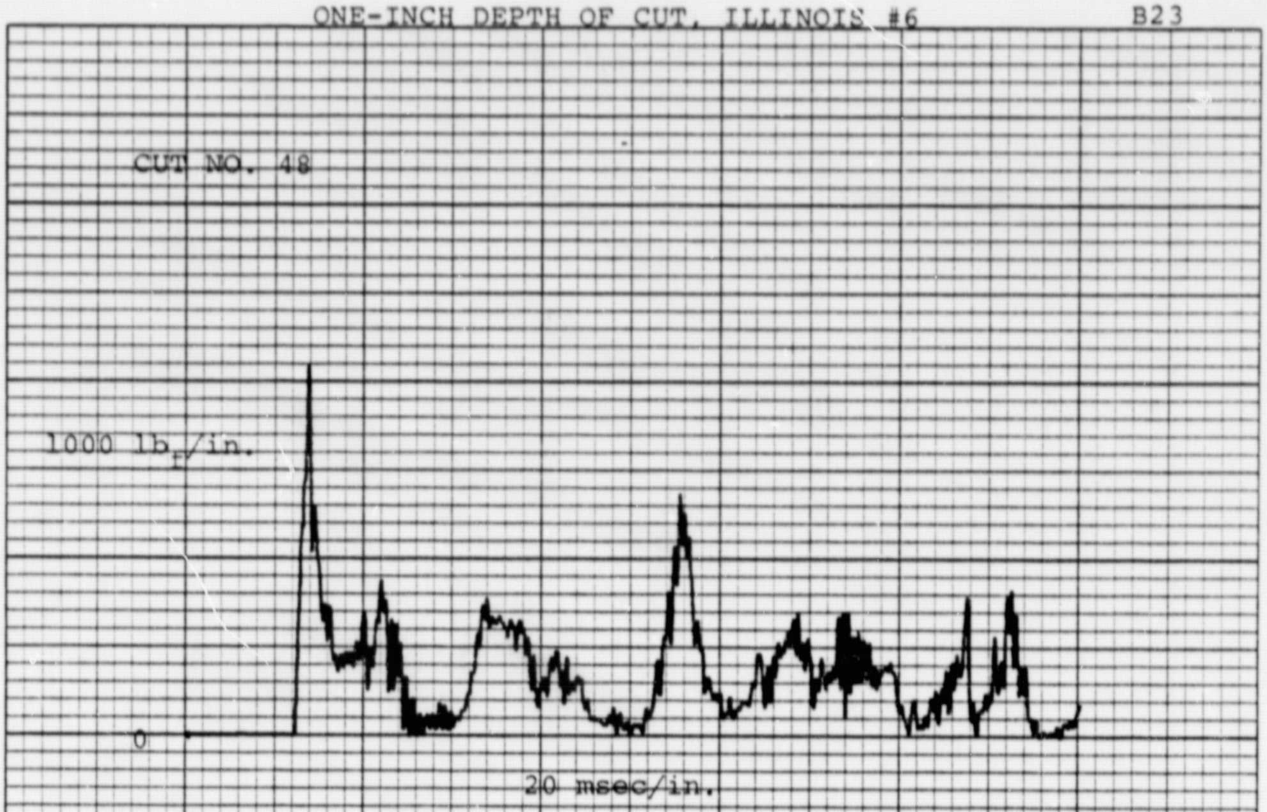


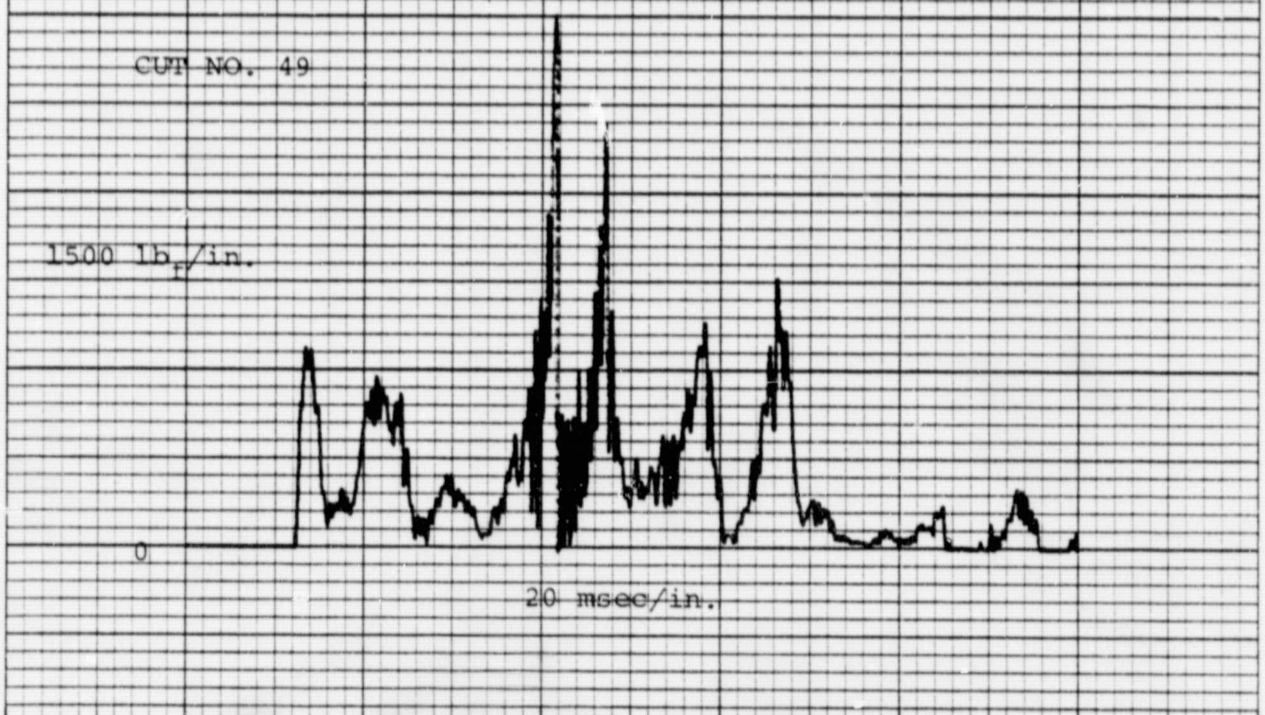
B22

ONE-INCH DEPTH OF CUT, ILLINOIS #6

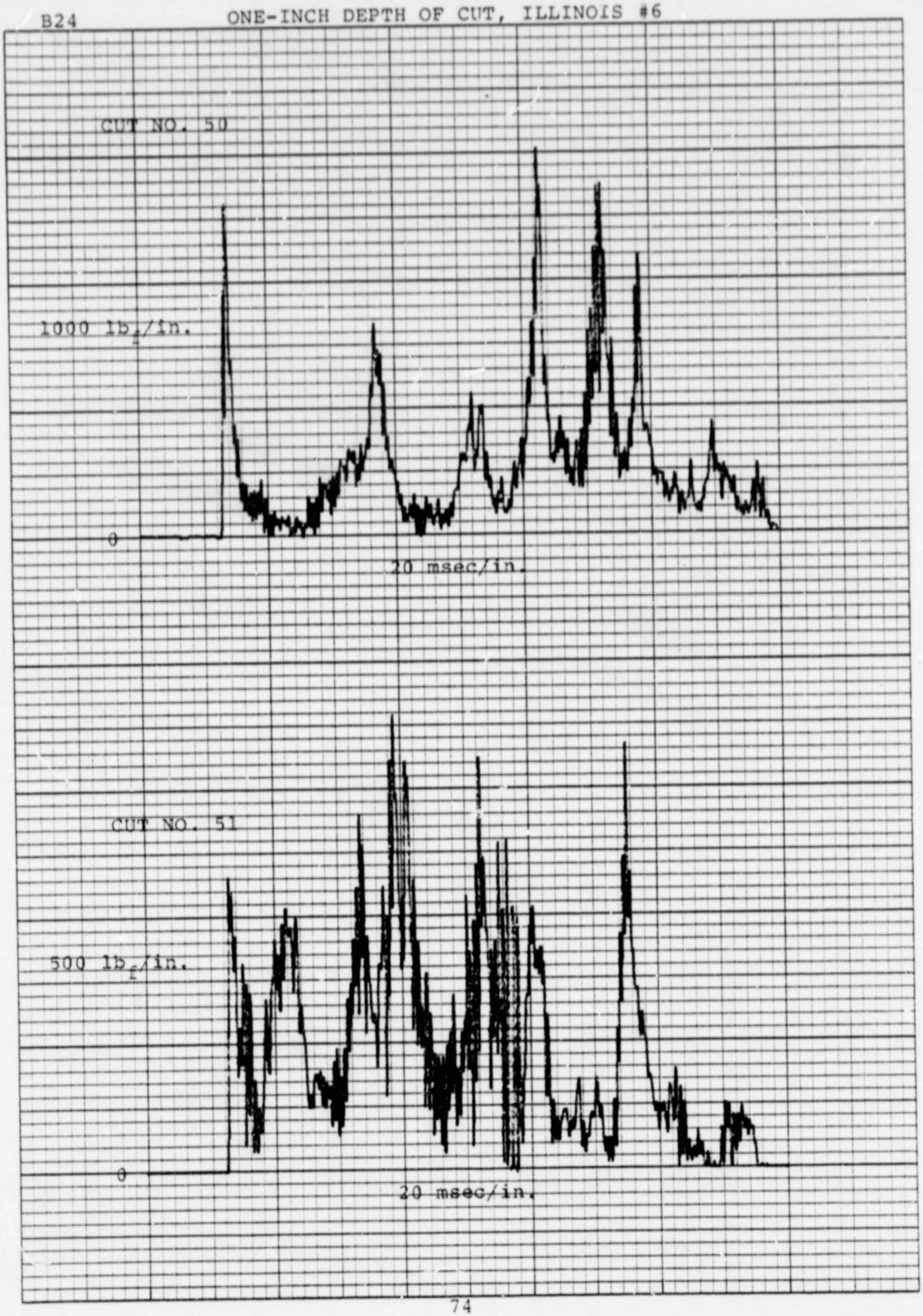


ONE-INCH DEPTH OF CUT, ILLINOIS #6

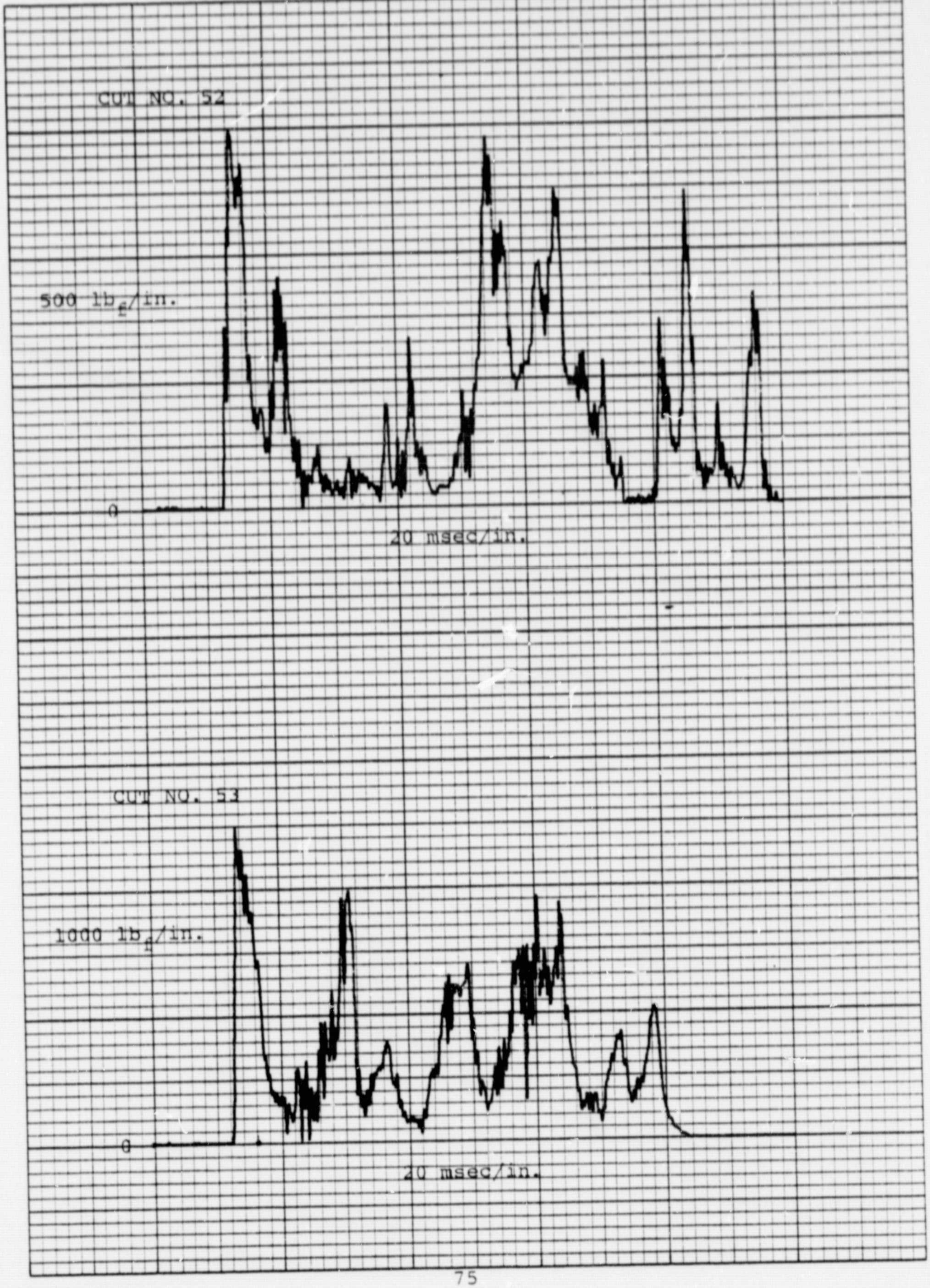




B24 ONE-INCH DEPTH OF CUT, ILLINOIS #6

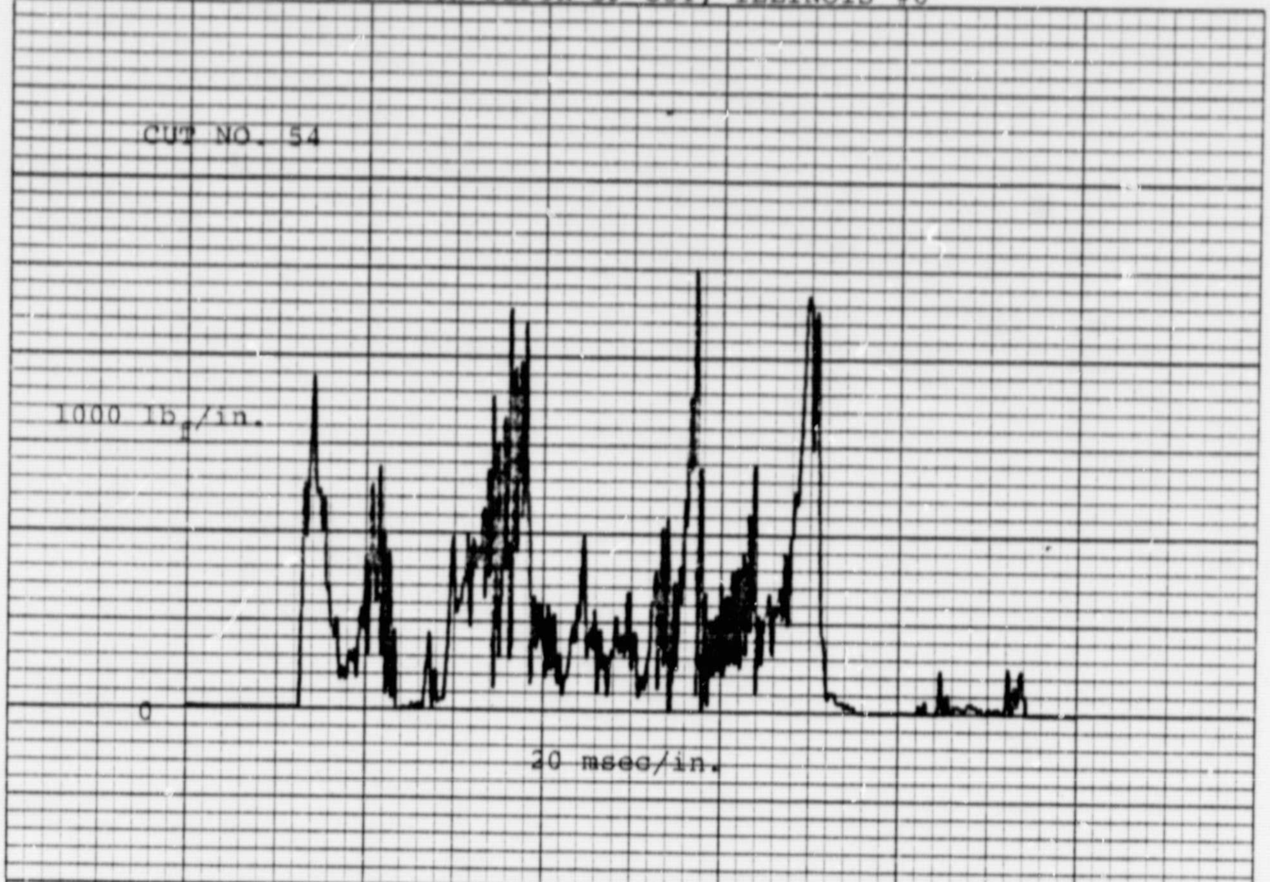


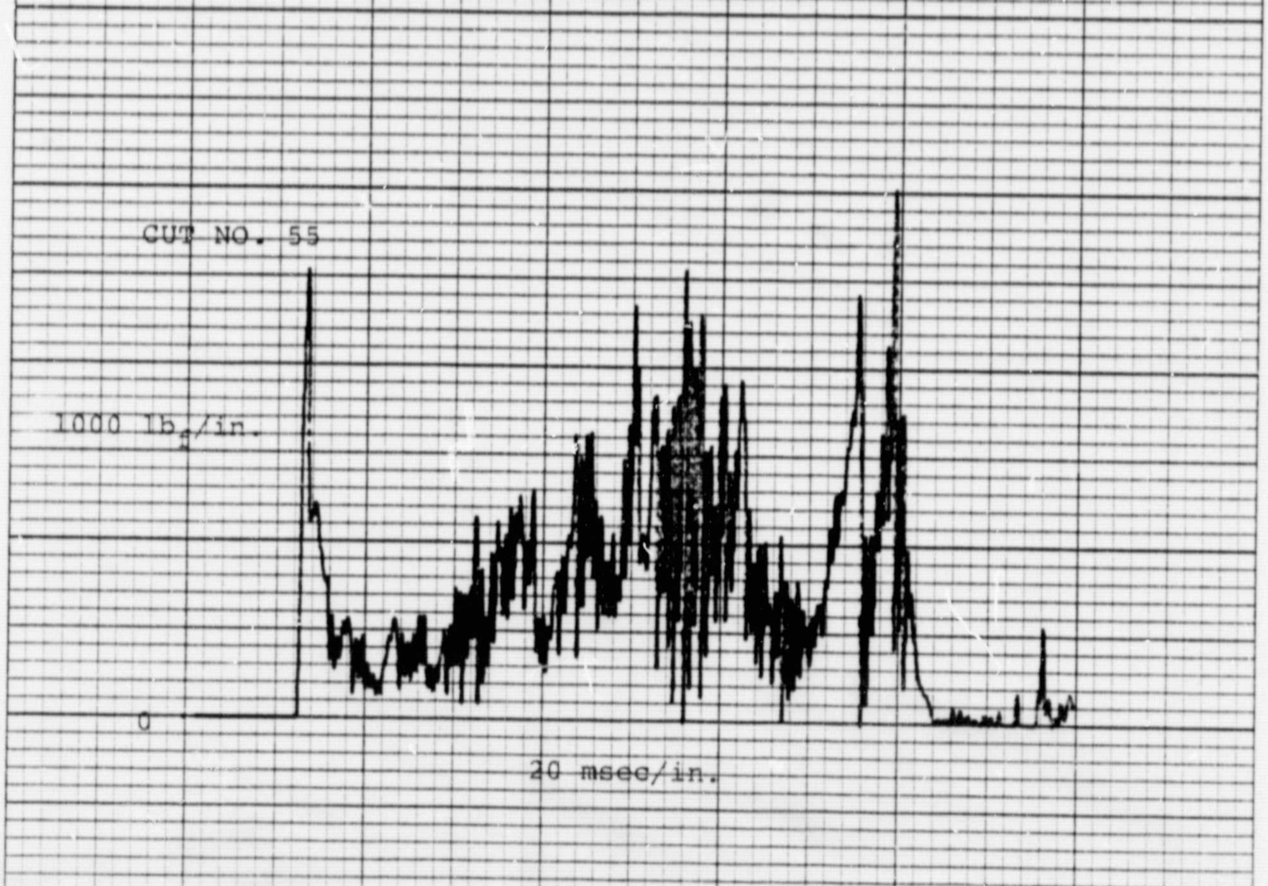
ONE-INCH DEPTH OF CUT, ILLINOIS #6



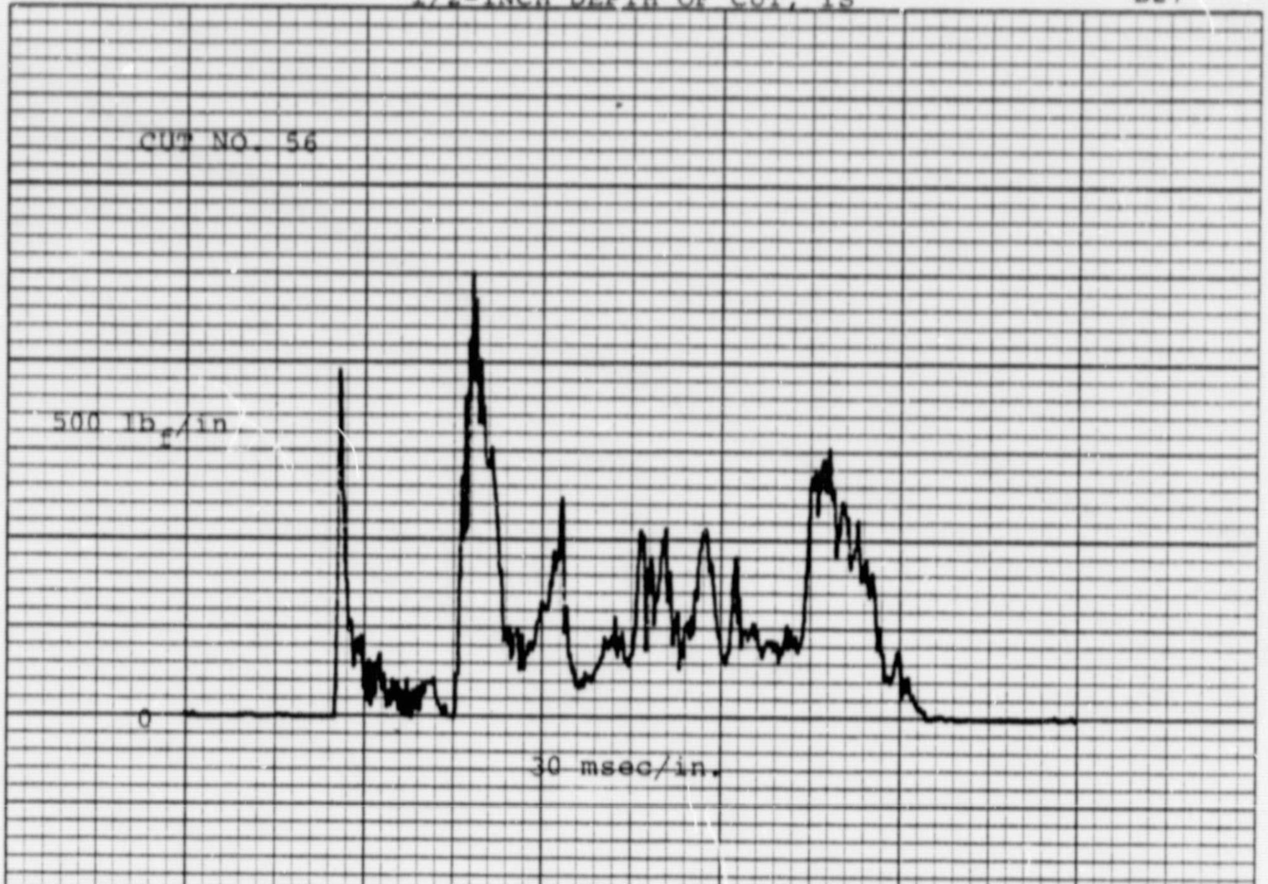
B26

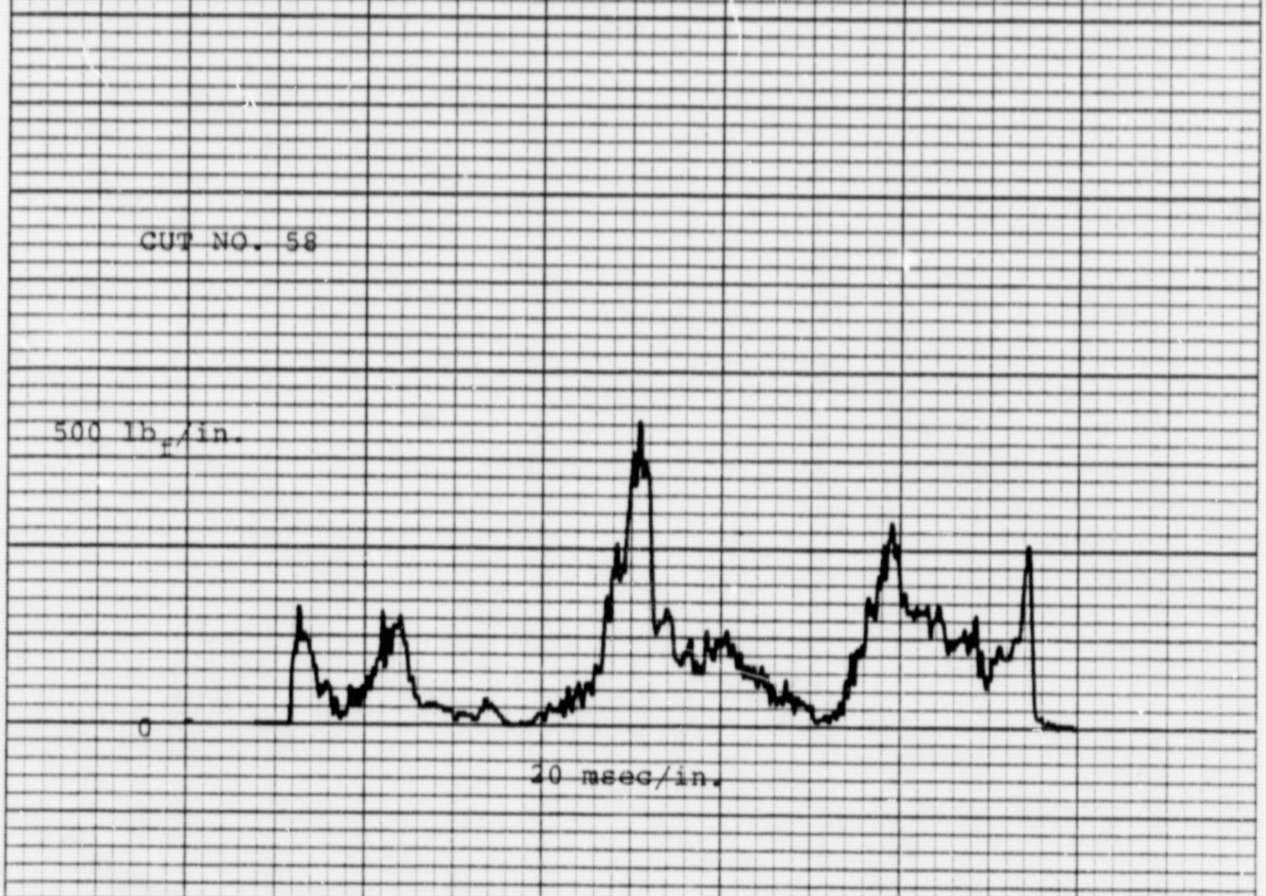
ONE-INCH DEPTH OF CUT, ILLINOIS #6



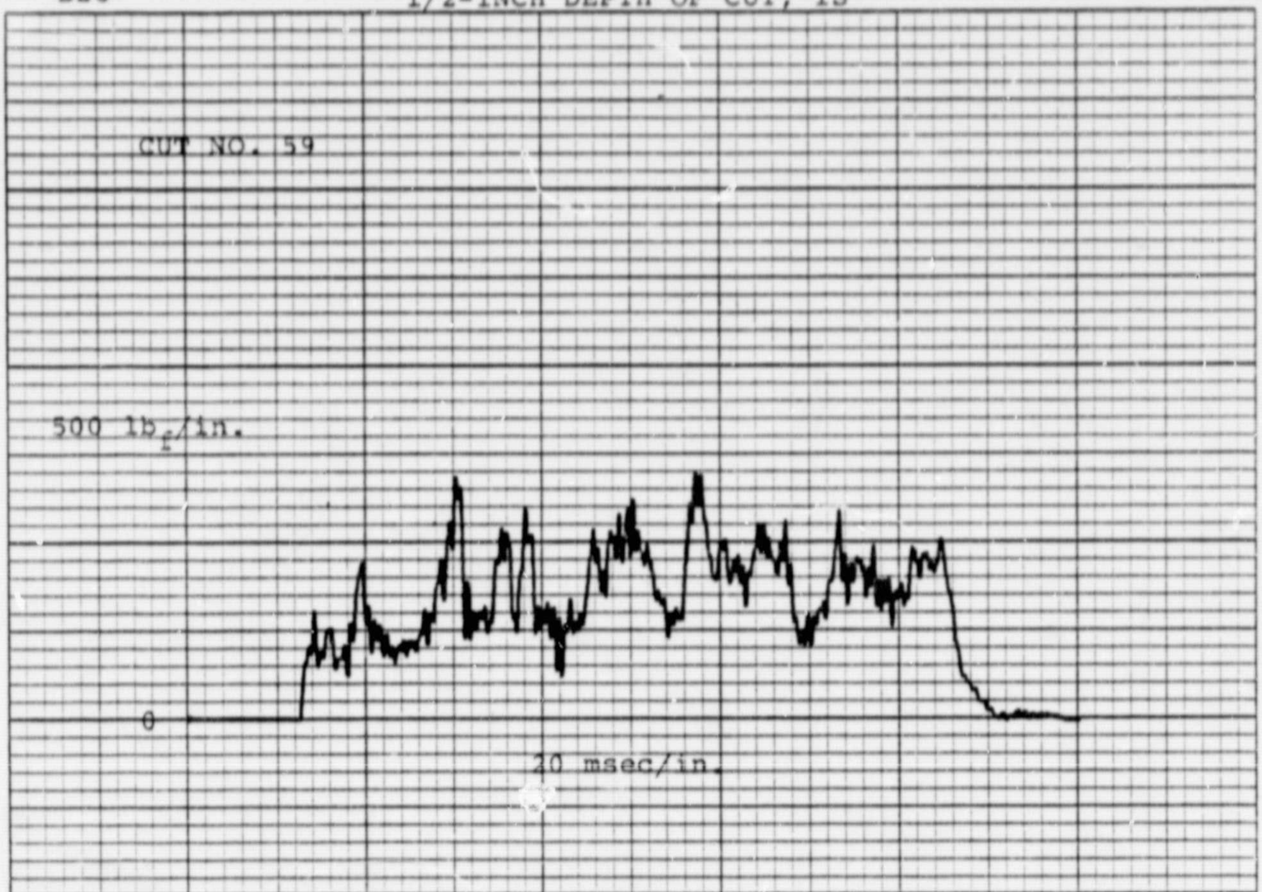


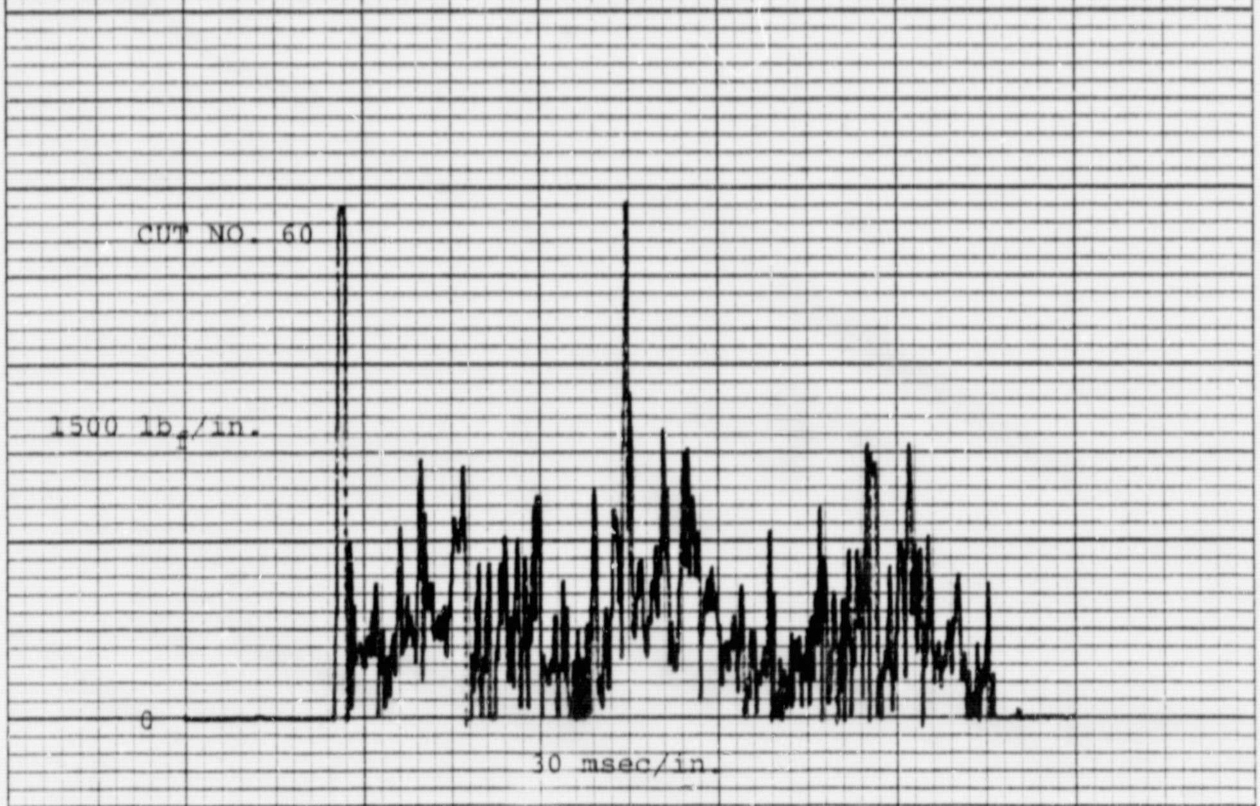
1/2-INCH DEPTH OF CUT, IS





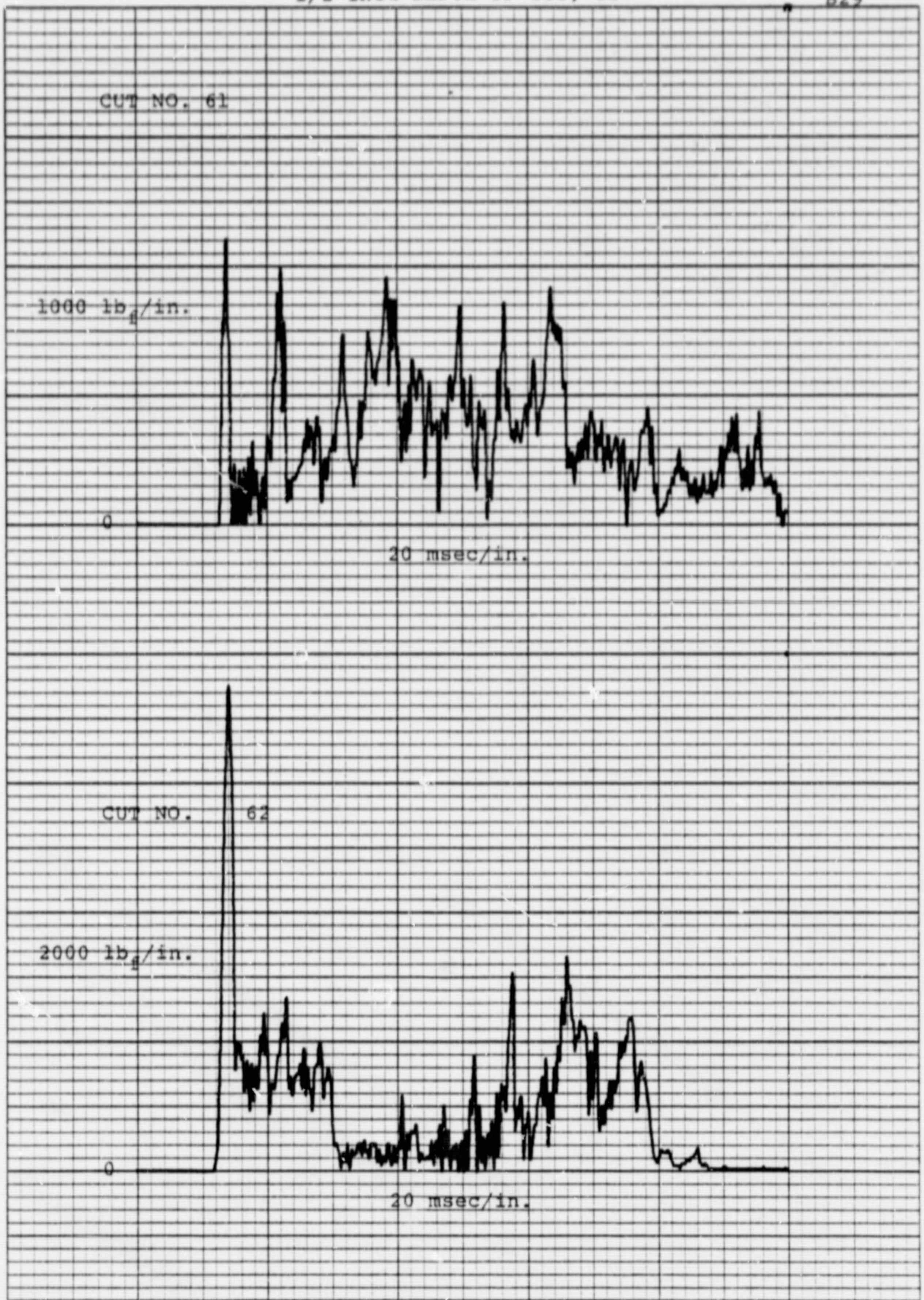
B28 1/2-INCH DEPTH OF CUT, IS



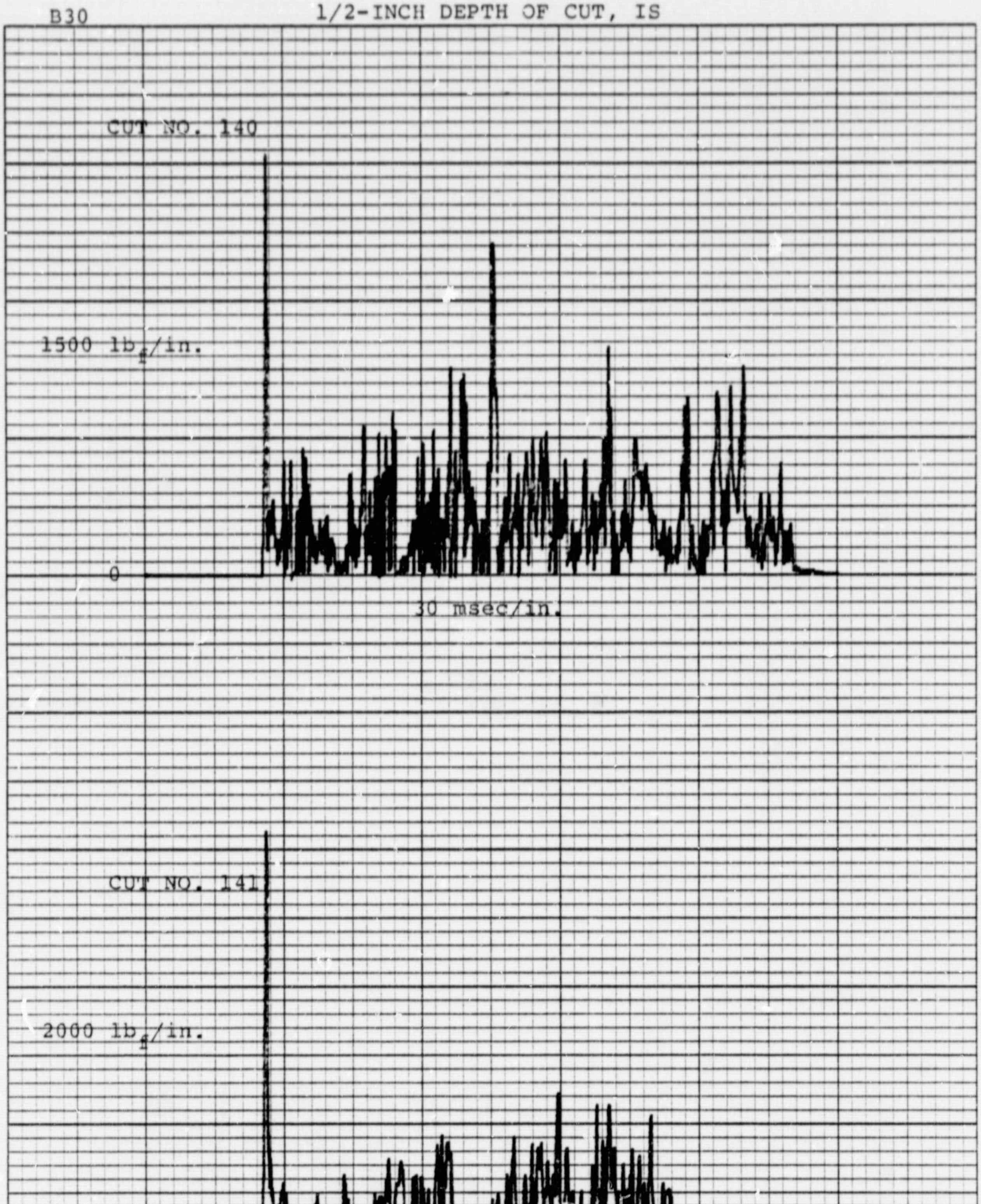


1/2-INCH DEPTH OF CUT, IS

B29

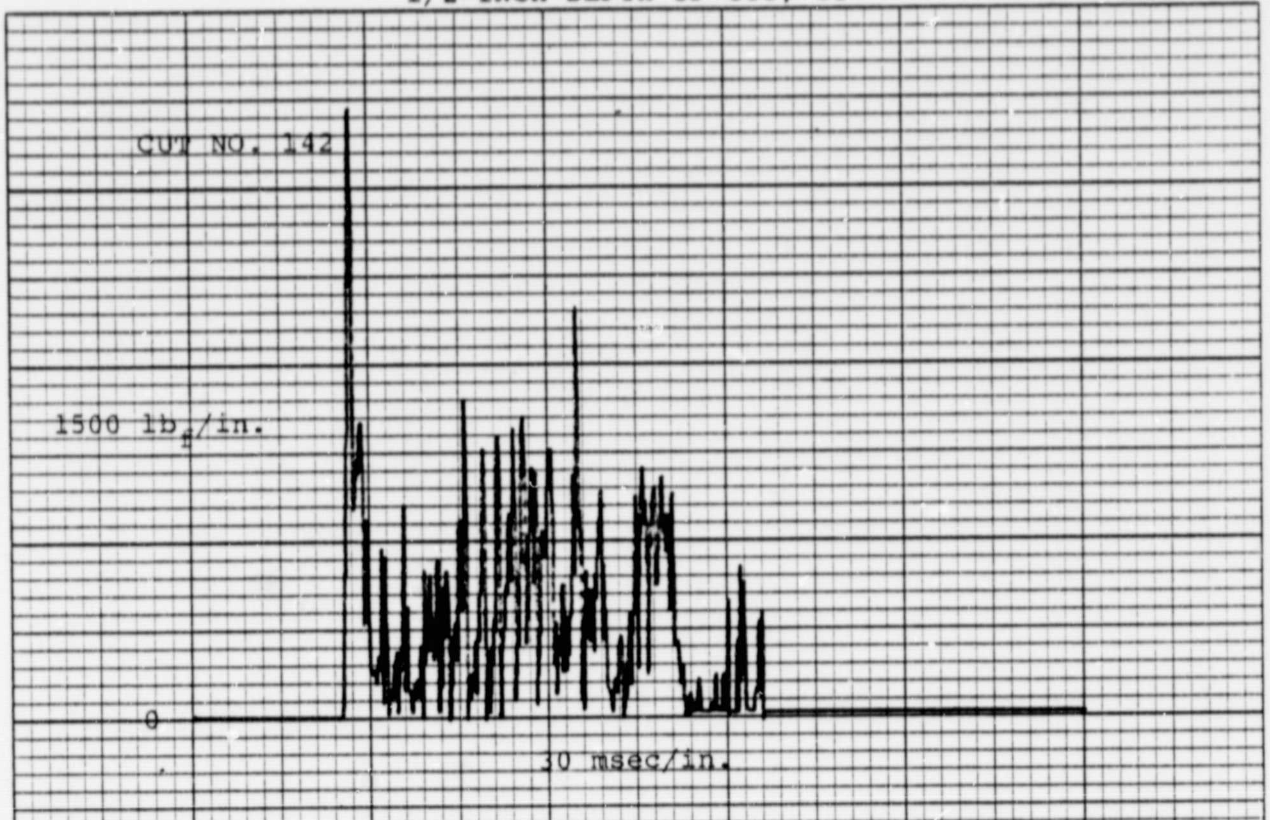


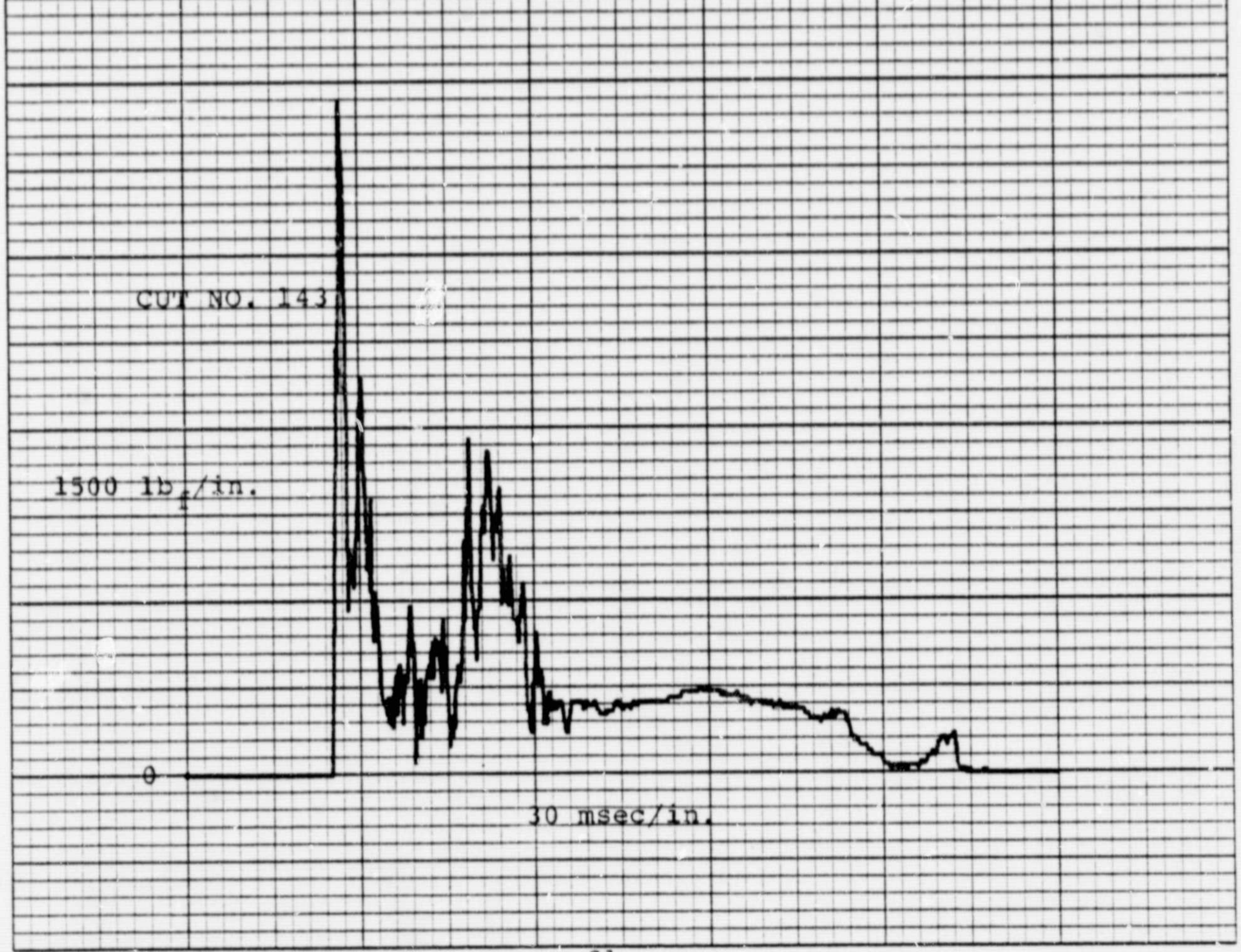
1/2-INCH DEPTH OF CUT, IS



1/2-INCH DEPTH OF CUT, IS

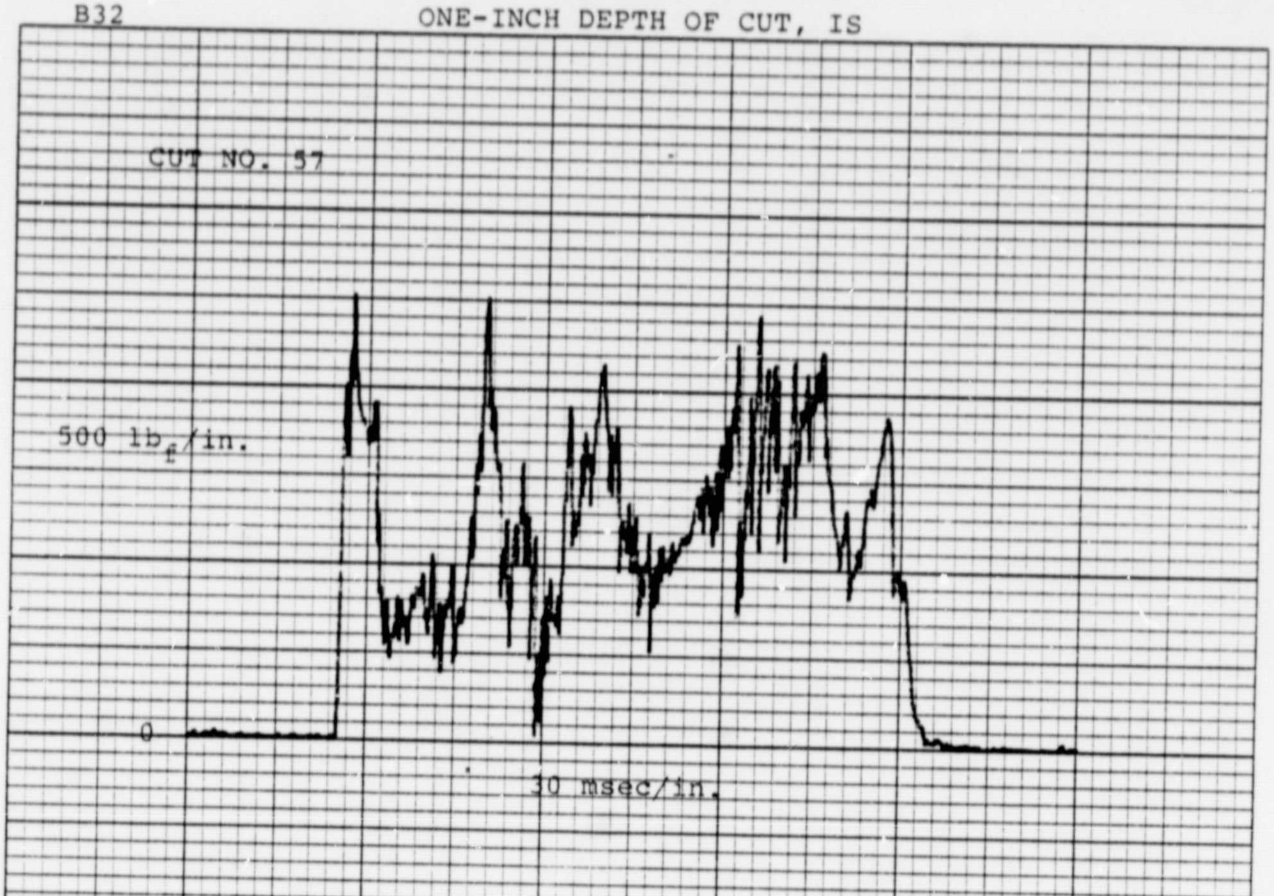
B31

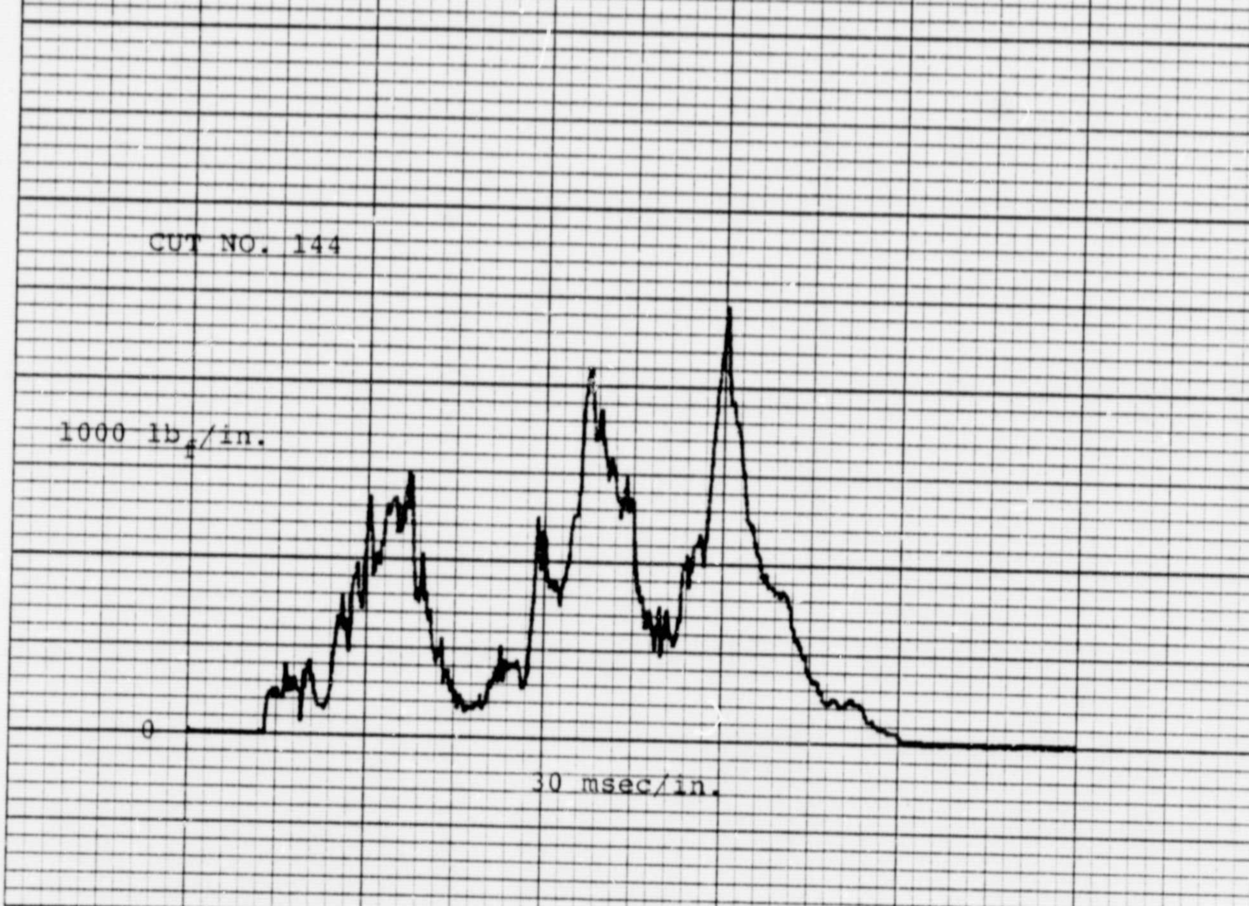




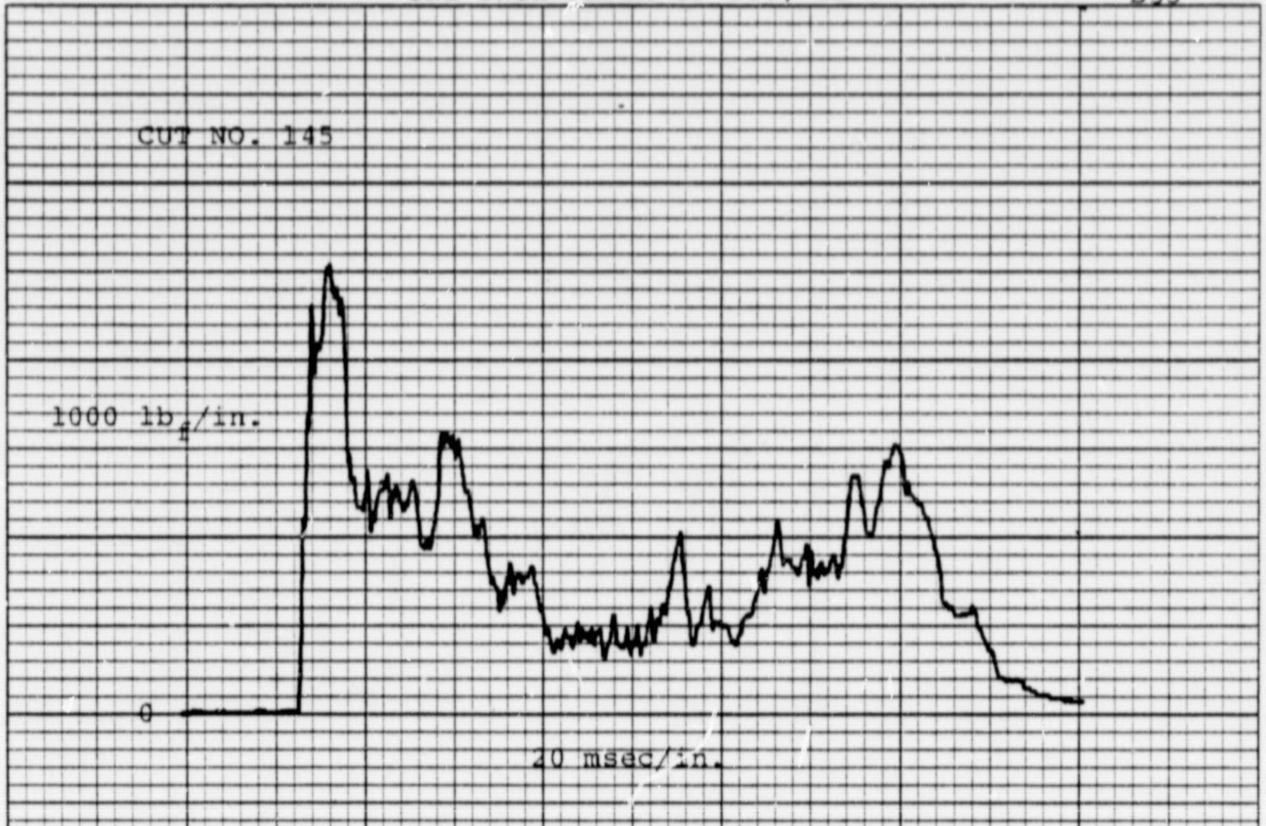
B32

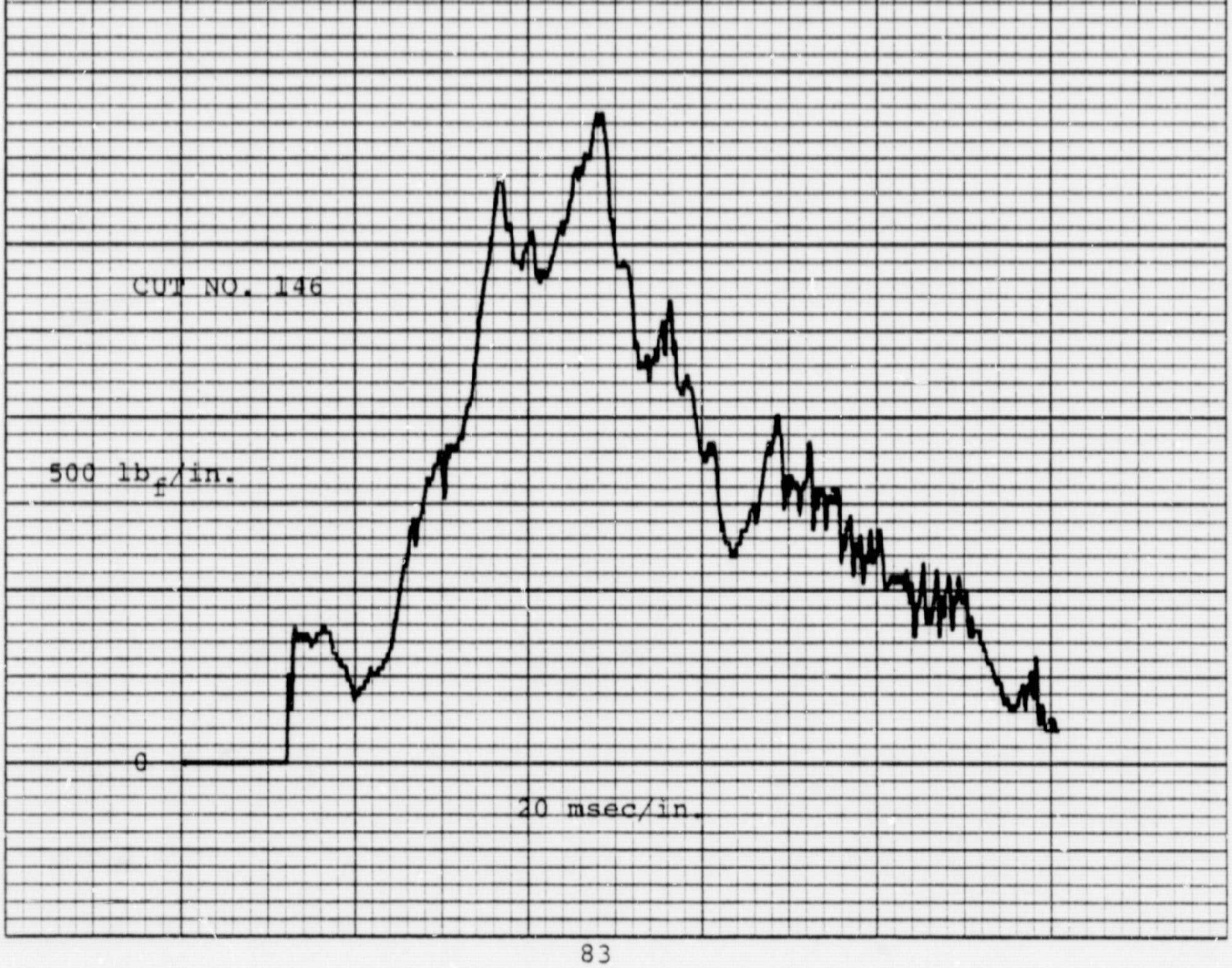
ONE-INCH DEPTH OF CUT, IS



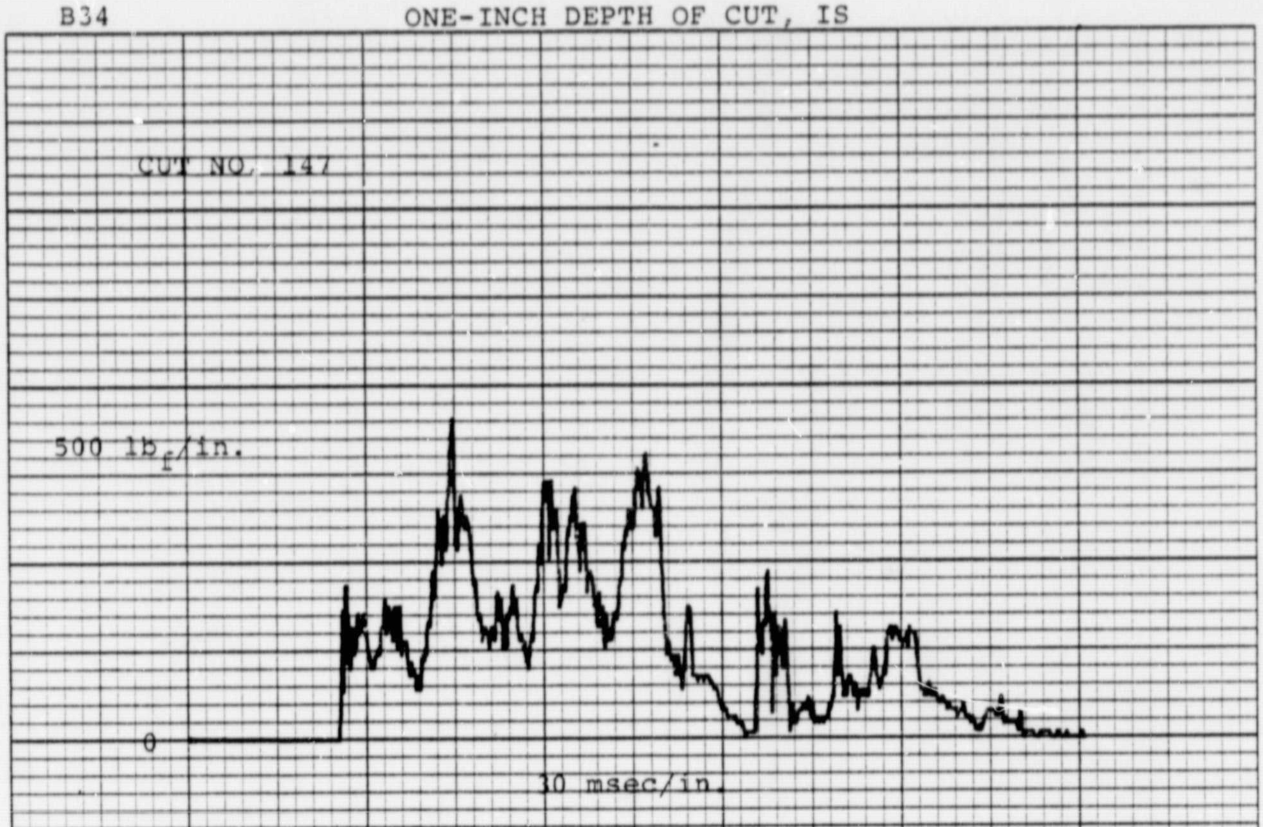


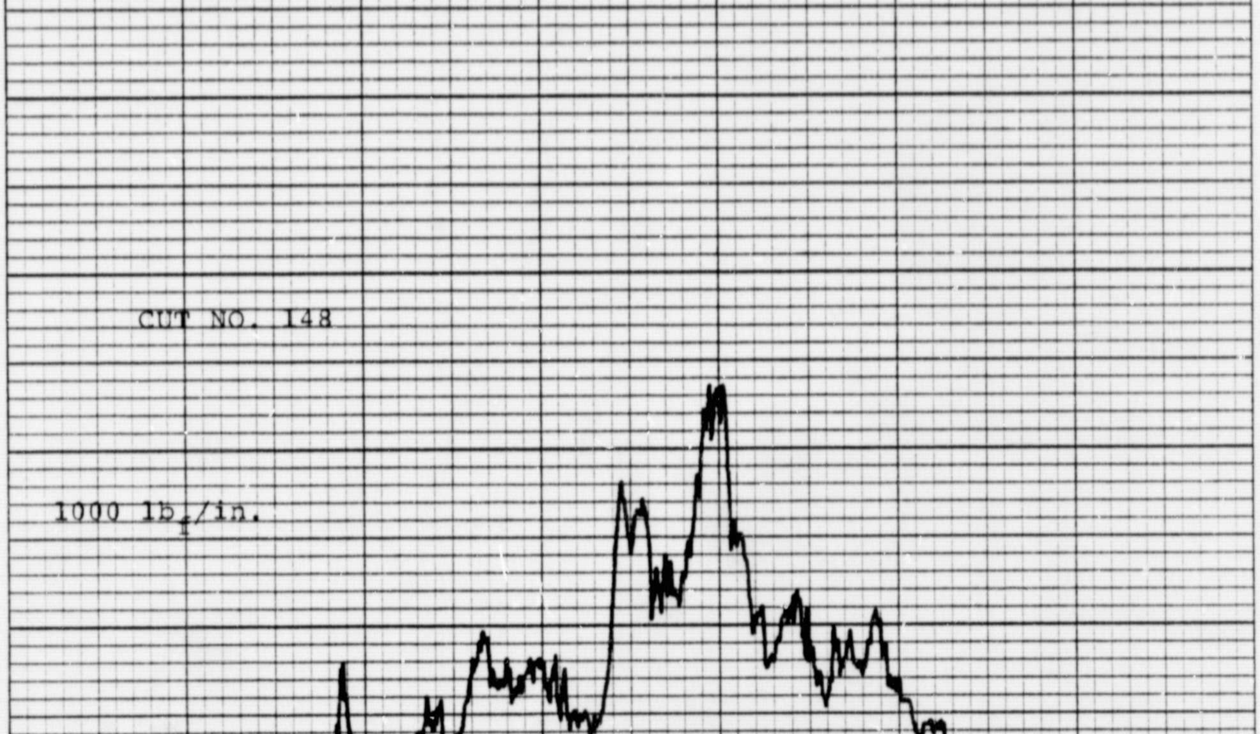
ONE-INCH DEPTH OF CUT, IS

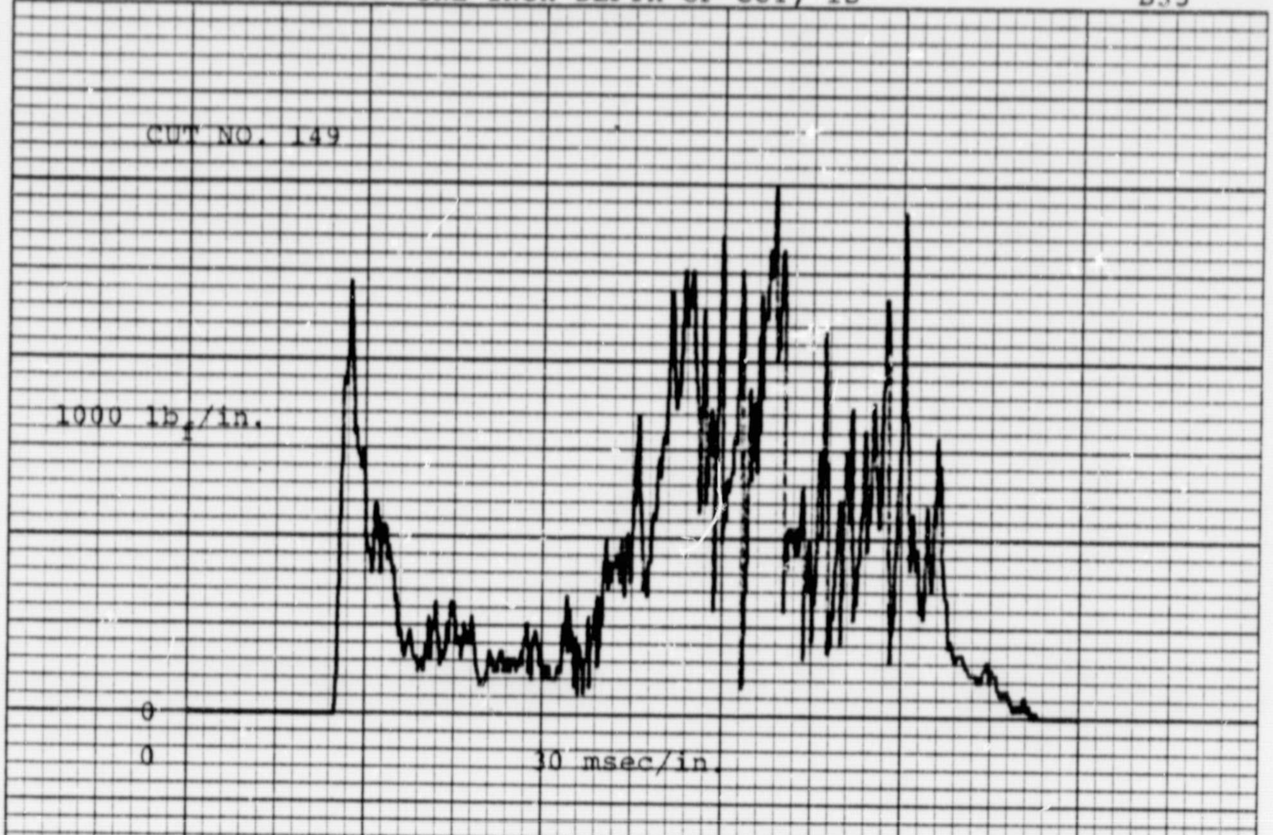


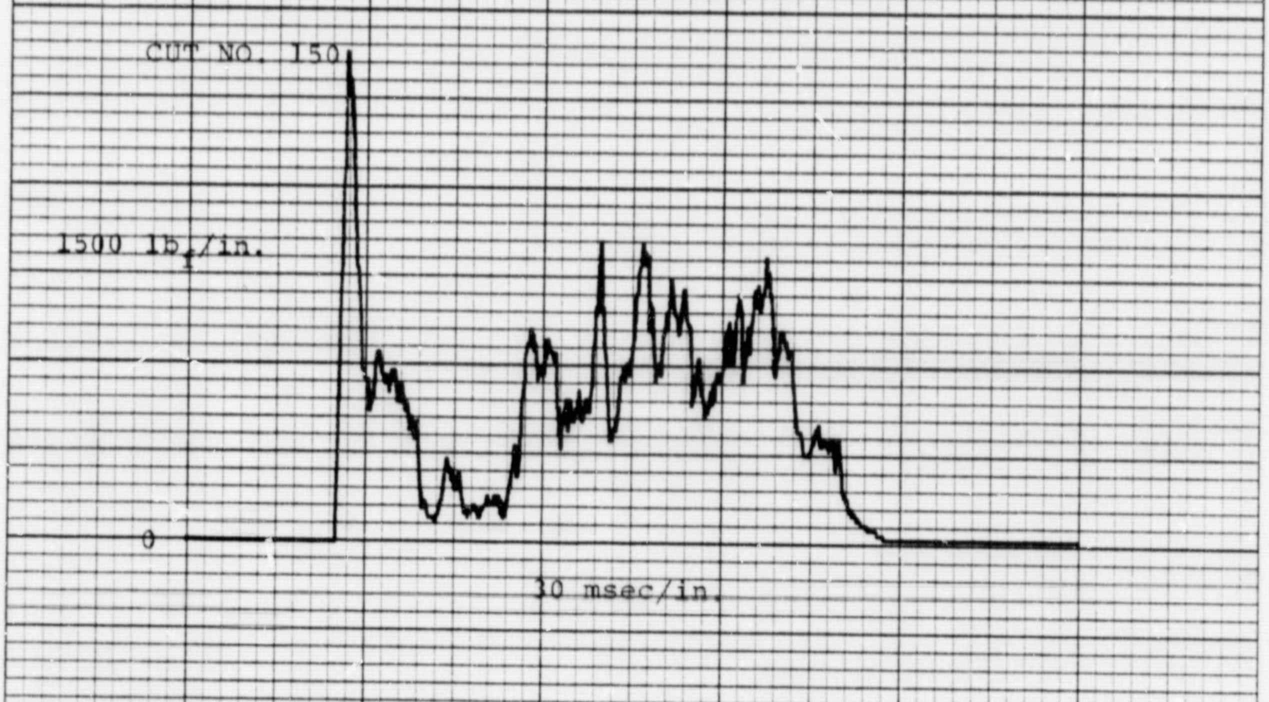


ONE-INCH DEPTH OF CUT, IS

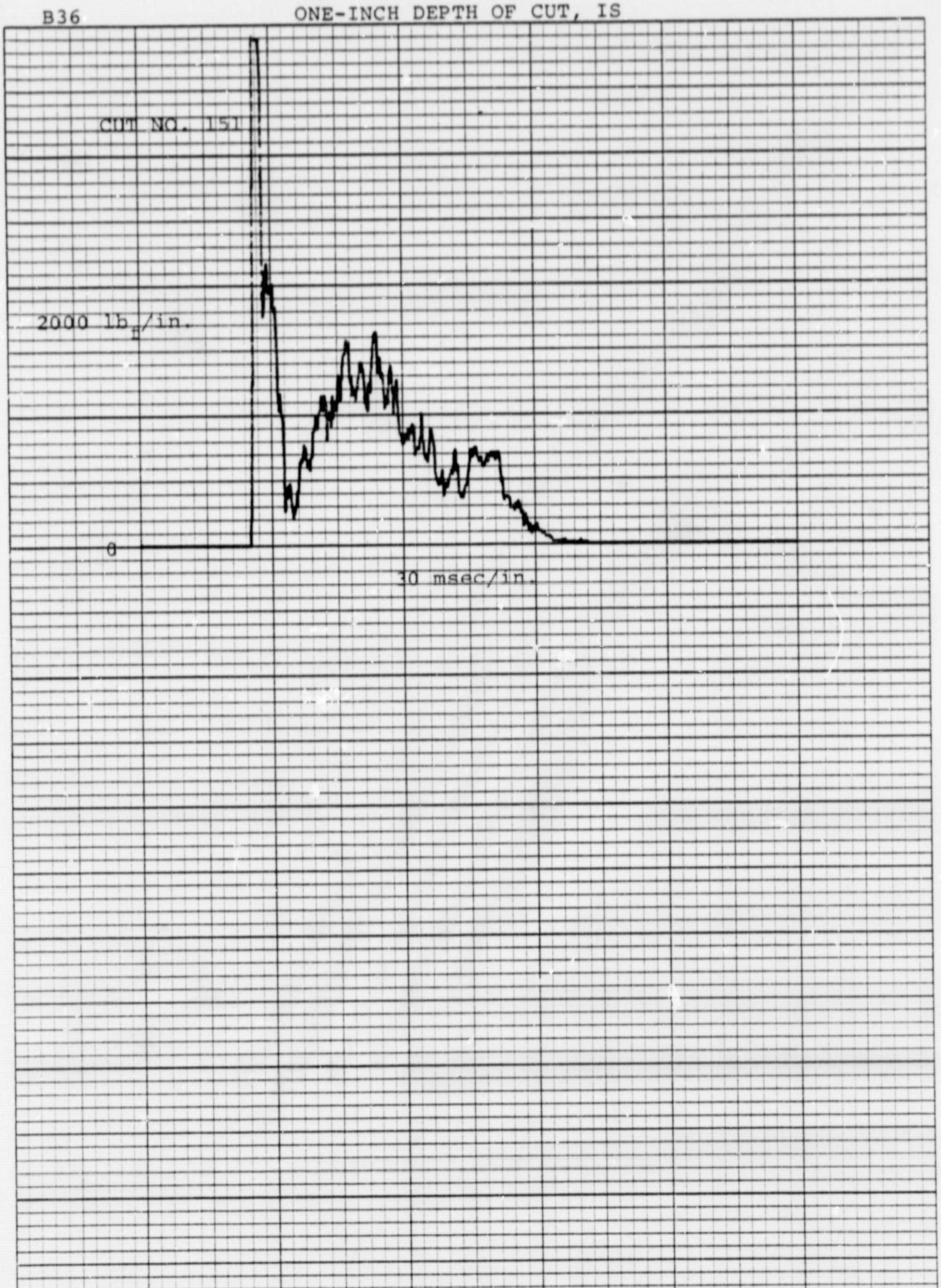




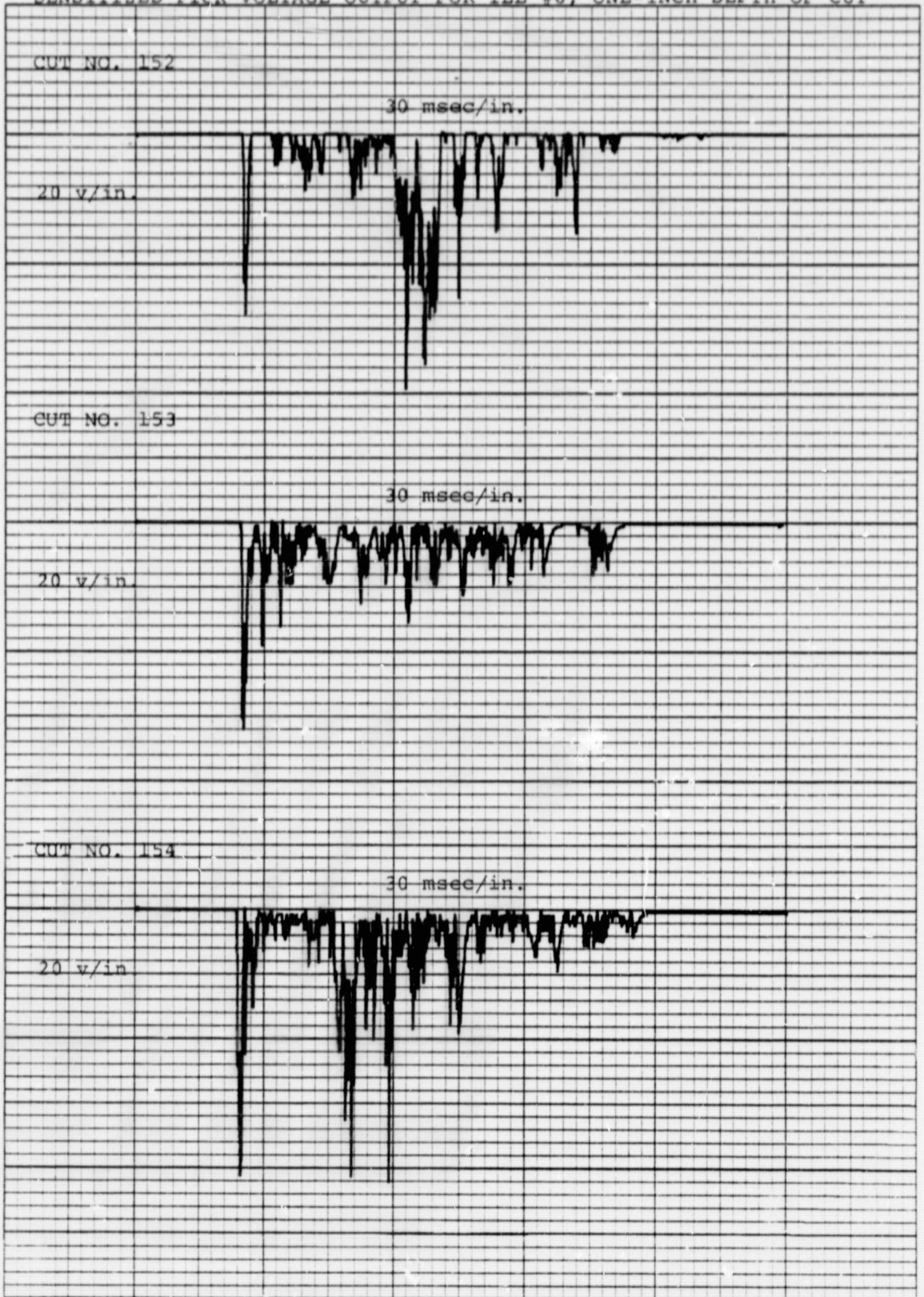

CUT NO. 149
1000 lb_f/in.
0
0
30 msec/in.


CUT NO. 150
1500 lb_f/in.
0
30 msec/in.

B36 ONE-INCH DEPTH OF CUT, IS

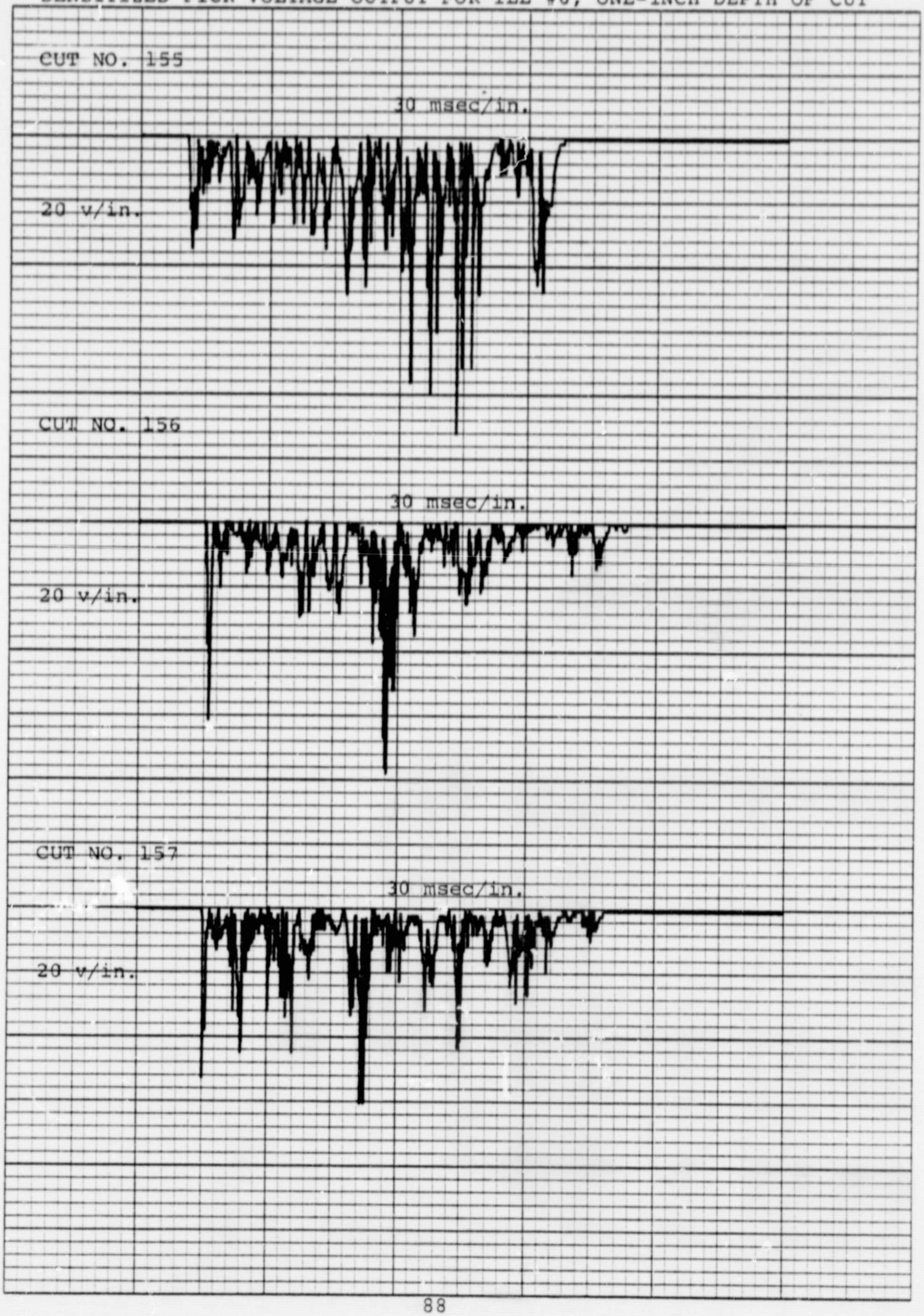


SENSITIZED PICK VOLTAGE OUTPUT FOR ILL #6, ONE-INCH DEPTH OF CUT



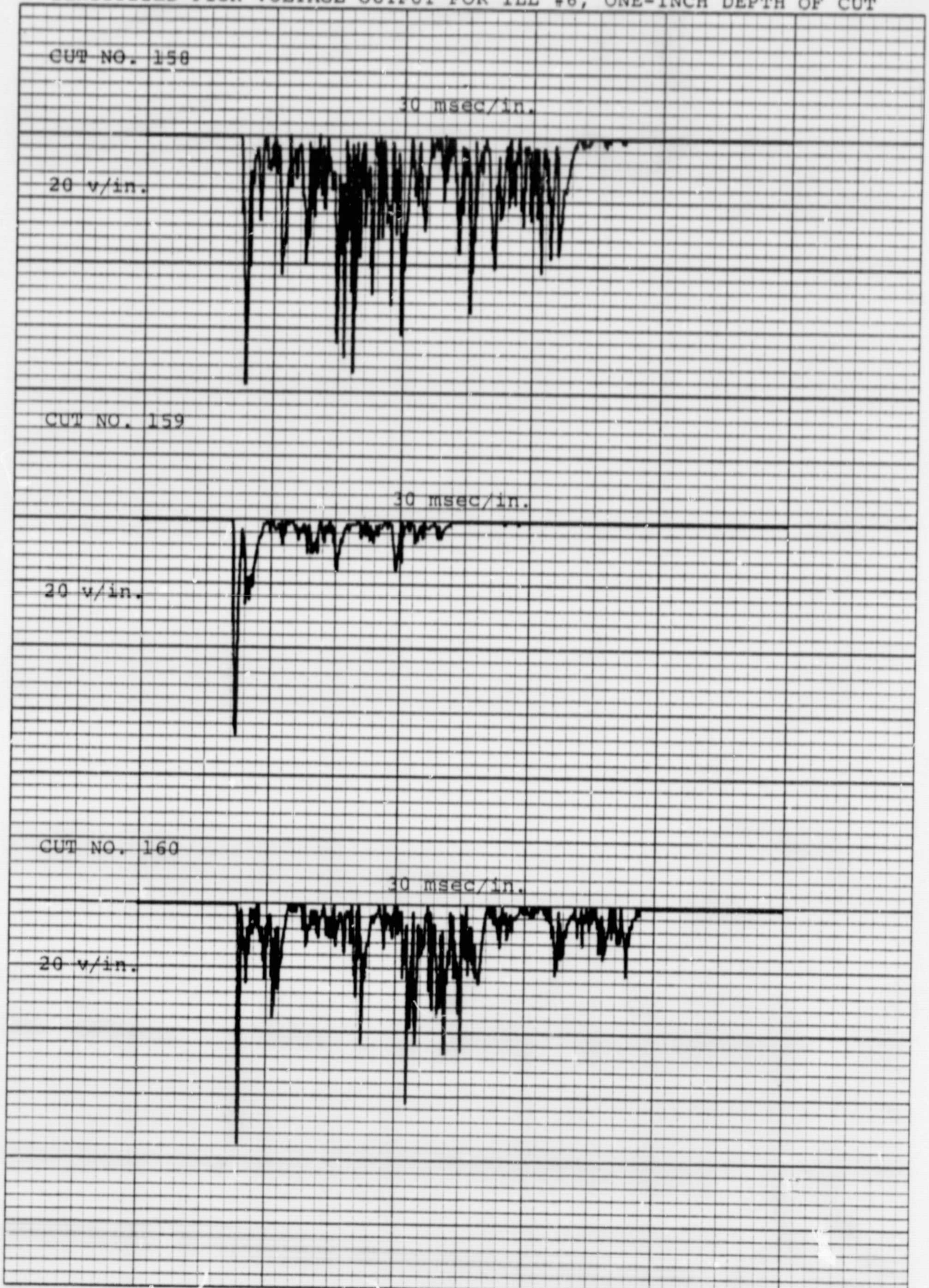
B38

SENSITIZED PICK VOLTAGE OUTPUT FOR ILL #6, ONE-INCH DEPTH OF CUT



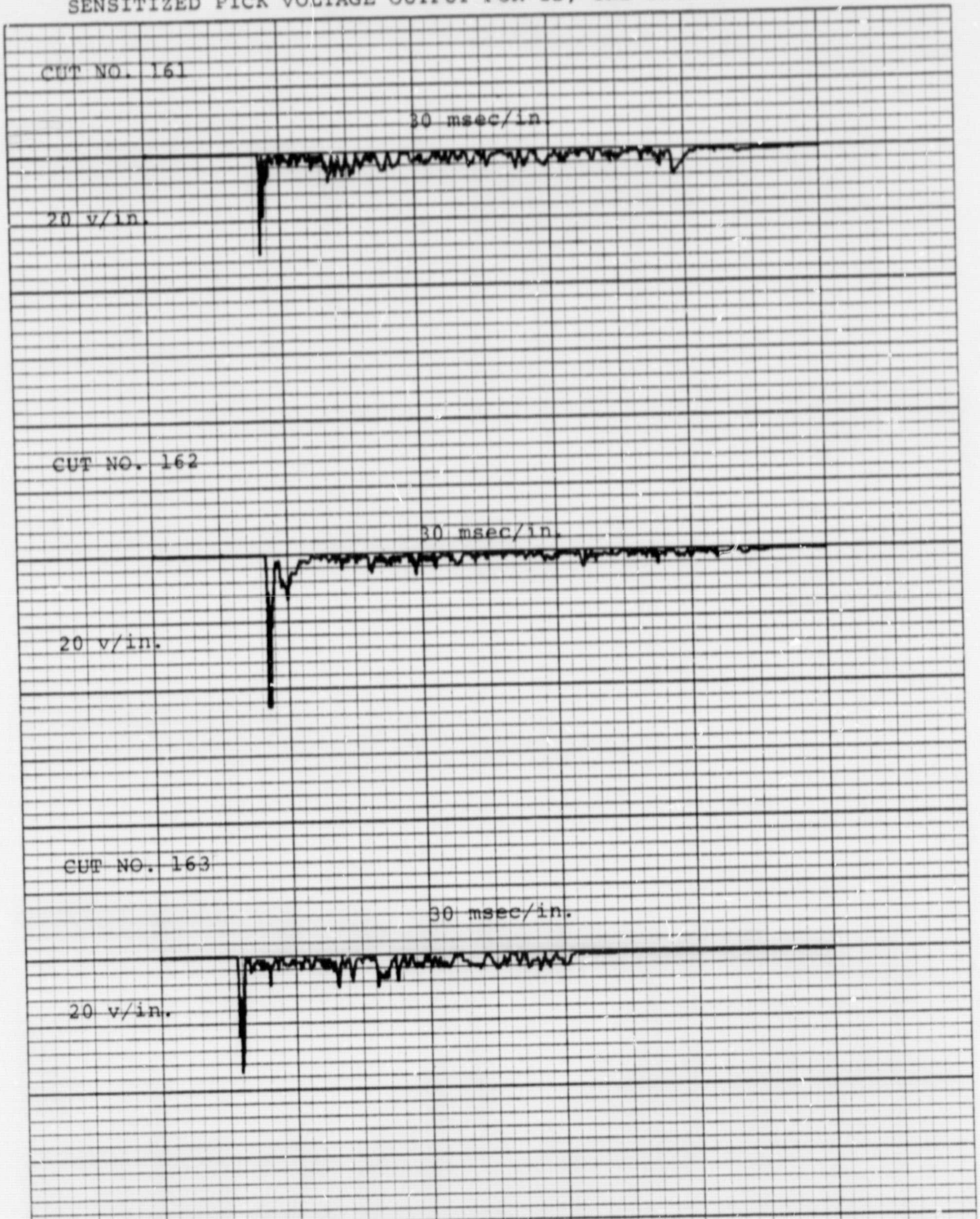
ORIGINAL PAGE IS
OF POOR QUALITY

SENSITIZED PICK VOLTAGE OUTPUT FOR ILL #6, ONE-INCH DEPTH OF CUT



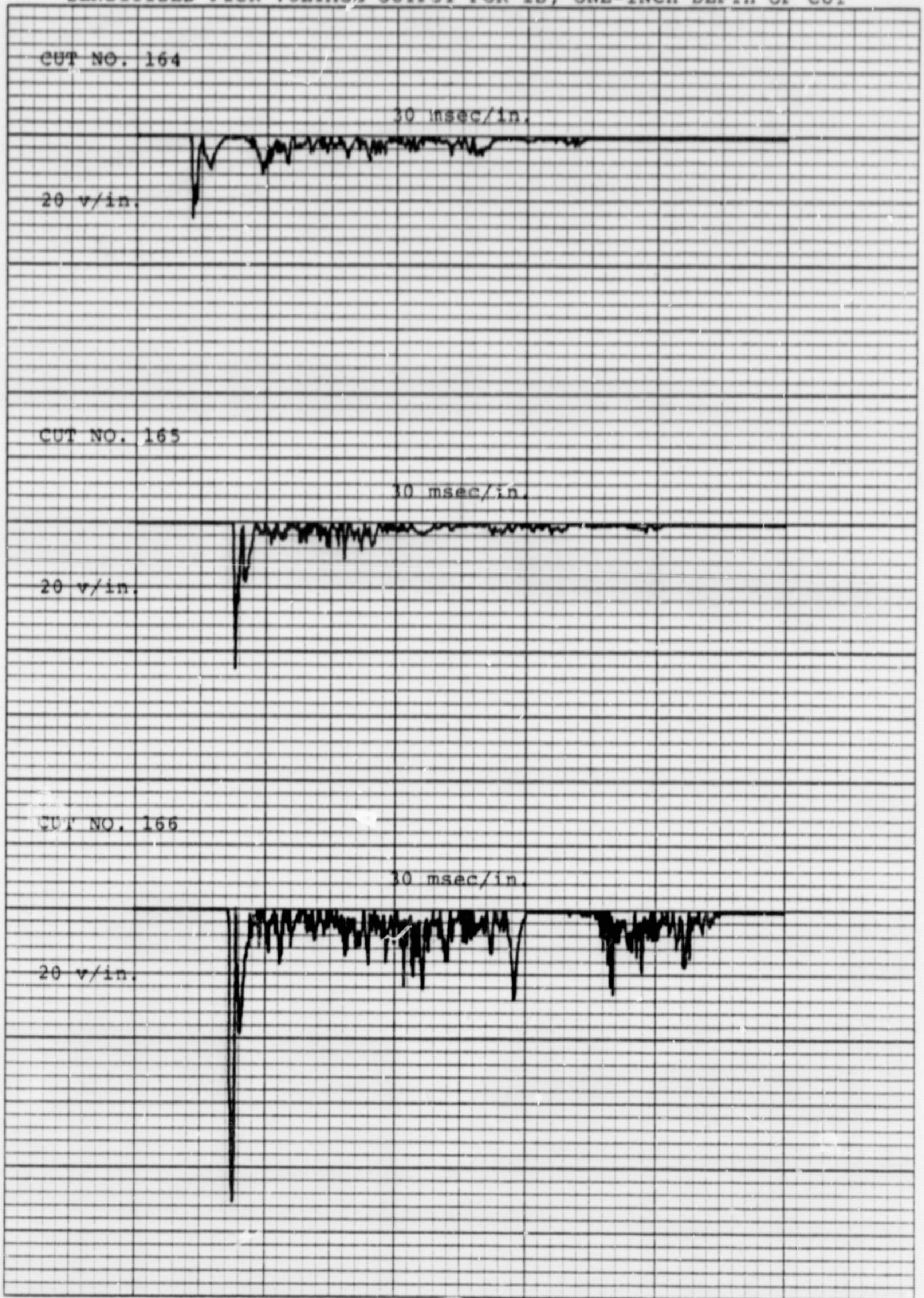
B40

SENSITIZED PICK VOLTAGE OUTPUT FOR IS, ONE-INCH DEPTH OF CUT



ORIGINAL PAGE IS
OF POOR QUALITY

SENSITIZED PICK VOLTAGE OUTPUT FOR IS, ONE-INCH DEPTH OF CUT



B42

SENSITIZED PICK VOLTAGE OUTPUT FOR IS, ONE-INCH DEPTH OF CUT